GENETIC VARIATION IN LAMB GROWTH AND CARCASS COMPOSITION

by

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DECLARATION

I hereby declare that this thesis, submitted in candidature for the degree of Philosophiae Doctor in the Faculty of Science, University of Edinburgh, does not include work submitted for any other degree or professional qualification. The thesis was composed by me and is a report of my analyses of data which were collected from experiments designed and run by members of the staff of the ARC Animal Breeding Research Organisation and of the Meat and Livestock Commission.

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ABSTRACT

The results of two experiments designed to examine the effects of genetic and environmental factors on the liveweight growth and carcass composition of cross-bred lambs are reported.

In the first experiment, data were available for the progeny of Dorset Down, Ile de France, Oldenburg, Oxford, Suffolk and Texel sires out of Border Leicester × Scottish Blackface and ABRO Dam Line (5 strains) × Scottish Blackface ewes. Analyses were made for (a) growth traits to 12 weeks for 2585 lambs, the progeny of 102 sires; (b) growth traits to slaughter at fixed weights of 35 kg and 40 kg for 1884 lambs (79 sires); and (c) half carcass dissection traits for 956 lambs (65 sires).

Sire breed, year, sex, rearing type, ewe age and other environmental factors significantly affected liveweight growth traits, percentage carcass composition and the distribution of dissectible lean tissue and subcutaneous fat between eight standard joints. Paternal half-sib estimates of the heritability of liveweight growth rates to slaughter were low (0.10 ± 0.06). Moderate heritability estimates were recorded for percentage lean in the carcass (0.41 ± 0.13), lean tissue and subcutaneous fat distribution. Estimates of the genetic and phenotypic correlations between traits are also presented.

In the second experiment the range of sire breeds was extended to include the Southdown and Cotswold. Data for 511 lambs, the progeny of 4 to 8 sires/breed and serially slaughtered at 13, 17, 21, 25, 29, 33, 37, 41, 51 and approximately 63 weeks of age, were analysed using the allometric equation. Analyses of the growth of

dissectible carcass tissues relative to age, liveweight and side weight, of dissectible subcutaneous, intermuscular and kidney knob and channel fat relative to lean tissue weight, and of lean tissue relative to bone weight, are reported.

In general, the effects of breed, year, ewe age, rearing type and sex upon differential growth patterns were not significant ($P > 0.05$). However, significant ($P < 0.05$) effects of sire breed and of environmental factors on intercepts are reported.

CONTENTS

CHAPTER 1

INTRODUCTION

Lamb meat production in the United Kingdom is characterised by wide variation both in market requirements and in the breeds and production systems supplying the market. During the past decade lamb meat producers have met increasing pressures to adapt to changes in demand and to exploit markets which have expanded since the accession of the United Kingdom to the European Economic Community. There is increasing pressure from the consumer for leaner meat and yet Kempster (1979) has estimated that between 15% and 20% of total carcass weight production may be fat in excess of consumption. There is therefore a need to investigate methods of improving carcass composition to meet consumer requirements by the manipulation of genotype and environment. However, ideal carcass composition must not be achieved at the expense of liveweight growth rate and efficiency of production.

The genetic contribution of the Down breeds to lamb carcass meat production has been estimated as 37% with a contribution of 60% to the genetic input of sires of slaughter lambs (Meat and Livestock Commission, 1972). The Suffolk breed alone was estimated to provide 50% of the genes of sires of slaughter lambs. Despite this important role, very little was known in 1972 about the comparative performance of the various Down breeds or of possible alternative breeds. Similarly, little was known about within-breed variation in growth and carcass composition.

This Thesis is a report of two experiments, designed to compare sire breeds for meat production from cross-bred ewes on a single lowland farm. In the first experiment sire breed means and the effects of identifiable environmental factors on lamb growth, carcass composition and tissue distribution at fixed slaughterweights of 35 kg and 40 kg are reported. A genetic analysis of the within-breed variation of these traits and the genetic relationships between liveweight growth and carcass composition is also presented. In the second experiment lambs were serially slaughtered between 13 weeks and 15 months of age and the effects of breed and environmental factors on the differential growth of the carcass tissues was studied.

CHAPTER 2

FACTORS AFFECTING LAMB CARCASS COMPOSITION

2.1 INTRODUCTION

There are a number of approaches to the study of the factors which affect lamb carcass composition. Survey data, Kempster and Cuthbertson (1977) and Wood, MacFie, Pomeroy and Twinn (1980), can provide valuable information about commercially important variation in lamb carcass composition but suffer from a confounding of genetic and environmental effects. Experiments carried out within specified environments with slaughter at fixed points within the commercial range of slaughter age, weight or finish may overcome this problem, but provide only limited information about the patterns of growth and development of the carcass. Serial slaughter experiments may vary in complexity of aims and design from those whose objectives are to describe carcass growth and development without reference to food inputs, e.g. Fourie, Kirton and Jury (1970), to those in which breed effects are studied against a range of nutritional treatments (e.g. Jackson, Weddell and Mansour, 1974). A range of mathematical models available for use in the analysis of serial slaughter data have been reviewed by Taylor (1978) and Finney (1978). The allometric equation, which has been most widely used in the study of the differential growth of the carcass tissues of domestic animals, is discussed in the following section.

2.1.1 The allometric equation

Huxley (1932) demonstrated the value of the allometric equation as a tool for the investigation of differential growth in a wide range

of organisms. This equation takes the form $y = ax^b$ where y is the weight of a part, x is the weight of the whole organism or another part and a and b are constants. The coefficient b represents a constant relationship between the specific growth rates of y and x such that:

$$(dy/dt)/y = b(dx/dt)/x \ .$$

Thus a small increase of m% in the weight of x is related to a an increment of bm% in the weight of y. If the data are transformed logarithmically the equation becomes

$$\log y = \log a + b.\log x$$

and this linear form is statistically easy to handle using standard least squares models (Seebeck, 1968). When $b = 1$ growth is said to be isometric, values of b which are greater than 1 indicate an increase in the proportion of y relative to x, similarly when $b < 1$ y declines relative to x. In the terminology of animal science an organ or tissue is said to be early maturing ($b < 1$) or late maturing ($b > 1$) relative to the independent variate.

The interpretation of the constant a has been considered by White and Gould (1965). Essentially log a defines the position of the regression line describing the relationship between log y and log x and represents the mean value of log y when $\log x = 0$ ($x = 1$). The value of log a is not unique and depends upon the units of measurement of x and y. Normally the units are chosen such that $x = 0$ represents a downward extrapolation beyond the range of the data. Cock (1966) pointed out two undesirable properties of log a; it is dependent upon errors in the estimate of the regression coefficient, and its error variance is higher than that of $\log \hat{y}$

for a value of log x close to the mean log $\bar{x}$. The position of the regression line is thus best defined as the value of log $\hat{y}$ at a defined value of log x close to, or identical with, log $\bar{x}$.

In recent years the simple allometric equation has been widely used in the analysis of carcass composition and tissue development in domestic animals. The attractive characteristic of the formula is that it allows the study of growth by relating the size of different parts of the body to absolute size, irrespective of age. However, it suffers from a number of theoretical and statistical limitations.

In studies of carcass composition the dependent variable often forms a large part of the independent variable. Correlations between the independent variable and the error may affect the significance of the effects being studied, e.g. breed, sex, rearing type.

When the least squares analyses are used to estimate the regression parameters the method is based upon assumptions that (1) error deviations occur only in the dependent variate and (2) the error variance of y is constant over the whole range of x. In the study of carcass composition x cannot be measured without error. This will lead to a downward bias in the estimate of the regression coefficient b (Cock, 1966). Methods of correcting for this bias have been considered by Kidwell and Chase (1967) but these generally involve *a priori* assumptions about the relative size of the error variance of x and y. Repeat measurements could be used to estimate these error variances but this is either difficult or impossible in carcass dissection work and only errors due to measurement (i.e. non-biological errors) would be included in the estimate (Cock, 1966).

The majority of studies are made over a limited range of liveweight and consequently transformation of the data to logarithms should overcome scale effects. In general allometric equations are used for comparative purposes and where absolute values of the regression parameters are not required least squares techniques may be considered satisfactory (Seebeck, 1968).

One advantage of the allometric equation is that in the logarithmic form it is approximately linear over a wide range of weights. However, deviations from linearity have not always been satisfactorily explored (Reeve and Huxley, 1945). One way is to divide the range (arbitrarily) into smaller data sets in which the linear relationship holds. This method of analysis has made a significant contribution to our understanding of growth patterns in domestic animals but is ultimately artificial and thus not entirely satisfactory. An alternative method is to fit a quadratic term $b_2(\log x)^2$ which indicates a constant shift in the ratio of the specific growth rates of the parts of interest. However higher order polynomials may also significantly improve the statistical fit of the model (e.g. Seebeck, 1966) in which case biological interpretation is difficult. Barton and Laird (1969) and Russell (1975) give examples of allometric analyses which showed linear relationships until the animal reached approximately 80% of mature size, beyond this stage of development deviations from simple allometry became important. Taylor (1978) suggests that the use of a logarithmic scale may put too much emphasis on early points whilst non-linearity may be obscured in later stages of growth.

2.2 GROWTH PATTERNS OF CARCASS TISSUES

2.2.1 Growth of lean, fat and bone

Summaries of published estimates of the allometric coefficients (b) for the growth of dissectible carcass lean, fat and bone are given in Tables 2.1 - 2.3. These results indicate that whichever independent variate is used, bone may be classified as an early maturing tissue ($b < 1$), fat as a late maturing tissue ($b > 1$) whilst lean gives intermediate values ($b \simeq 1$). Similar results are given for cattle (Berg and Butterfield, 1976) and for pigs (Davies, 1974a).

The allometric coefficients for the relationship between dissectible lean and empty body weight (Table 2.1) indicate that carcass lean constitutes a relatively constant proportion of the empty body over wide weight ranges. This is in agreement with the work of McClelland, Bonaiti and Taylor (1976) who reported constant proportions of lean in the empty body between 40% and 70% of mature size. However both Knapman (1976) and Prud'hon (1976) showed a slight tendency for the proportion of lean in the empty body to decline with increasing maturity. Bénévent (1971) found a significantly ($P = 0.01$) higher value for b in early postnatal growth than in later growth. No comparable data are available since few authors have reported experiments which included the dissection of new-born lambs or have tested for non-linearity in the log-log relationship (e.g. Fourie *et al*, 1970).

The allometric coefficients for the relationship between dissectible lean and carcass or side weight were all less than 1.0 indicating that lean constitutes a declining proportion of the carcass as carcass weight increases. Low values of b are particular noticeable in experiments where the animals were fed high concentrate diets

Table 2.1 Estimates of the allometric coefficient (b) for the relationships of carcass lean with empty body weight, carcass or side weight and muscle plus bone weight

Independent variate	Number and type of animals	b	Range in weight or age	Author(s)
Empty Body Weight	212, rams and ewes, Romney (R), Southdown (S), R × S	0.96±0.013 - 1.01±0.01	Birth - maturity	Fourie, Kirton & Jury (1970)
" " "	80, rams, Romanov (R), Merino (M), R × M, Berrichon (B), B × M	0.94 - 0.99	25 - 150 days	Prud'hon (1976)
" " "	12, rams and ewes, Merino d'Arles	1.14±0.07	Birth - 25 days, 3.93-9.13 kg	Bénévent (1971)
" " "	8, rams and ewes, Merino d'Arles	1.21±0.06	Birth - 12 days, 3.93-6.00 kg	" "
" " "	20, rams and ewes, Merino d'Arles	0.95±0.10	25 - 160 days, 9.13-25.32 kg	" "
" " "	57, various sources	1.02		Tulloh (1963)

Table 2.1 continued Estimates of the allometric coefficient (b) for the relationships of carcass lean with empty body weight, carcass or side weight and muscle plus bone weight

Independent variate	Number and type of animals	b	Range in weight or age	Author(s)
Carcass or side weight	133, castrates and ewes, Dorset Down × and Oxford ×	0.63 - 0.76	Oxford × 31-65 kg, Dorset × 30-55 kg	Wilson (1975)
" "	212, rams and ewes, Romney (R), Southdown (S), R × S	0.90±0.01 - 0.97±0.012	Birth - maturity	Fourie *et al* (1970)
" "	57, rams, wethers and ewes, Merino and Dorset Horn ×	0.98 ± 0.02	13.5 - 35.5 kg	Seebeck (1966)
" "	57, various sources	0.98		Tulloh (1963)
" "	27, wethers, Dorset Horn × Merino	0.82±0.06 - 0.94±0.07	15 - 40 kg, 3 nutritional treatments	Murray & Slezacek (1976)
Muscle + bone weight	212, rams and ewes, Romney (R), Southdown (S), R × S	1.05±0.01 - 1.06±0.01	Birth - maturity	Fourie *et al* (1970)
" "	133, wethers and ewes, Oxford and Dorset Down ×	1.07	Oxford × 31-65 kg, Dorset × 30-55 kg	Wilson (1975)
" "	10, wethers and ewes, Suffolk ×	1.10 ± 0.008	2.8-99 kg	Elsley, MacDonald & Fowler (1964)

Table 2.2 Estimates of the allometric coefficient (b) for the relationships of carcass fat with empty body weight, carcass or side weight and muscle plus bone weight

Independent Variate	b	Range in weight or age	Author(s)
Empty body weight	1.94±0.26	Birth - 25 days, 3.93-9.13 kg	Bénévent (1971)
" " "	1.45±0.06 - 1.75±0.03	Birth - maturity	Fourie, Kirton & Jury (1970)
" " "	1.54		Tulloh (1963)
" " "	1.36-1.83	25 - 150 days	Prud'hon (1976)
Carcass or side weight	1.35±0.14 - 1.67±0.28	15 - 40 kg, 3 nutritional treatments	Murray & Slezacek (1976)
" " " "	1.37±0.04 - 1.50±0.02	Birth - maturity	Fourie *et al* (1970)
" " " "	1.59		Tulloh (1963)
" " " "	1.38±0.06	13.5 - 35.5 kg	Seebeck (1966)
" " " "	1.68-1.91	Oxford × 31-65 kg, Dorset × 30-55 kg	Wilson (1975)
Muscle + bone weight	1.46±0.06 - 1.75±0.03	Birth - maturity	Fourie *et al* (1970)
" " " "	2.27	Oxford × 31-65 kg, Dorset × 30-55 kg	Wilson (1975)

Table 2.3 Estimates of the allometric coefficient (b) for the relationships of carcass bone with empty body weight, carcass or side weight and muscle plus bone weight

Independent Variate	b	Range in liveweight or age	Author(s)	
Empty body weight	0.69±0.09	Birth - 25 days, 3.93-9.13 kg	Bénévent	(1971)
" " "	0.78±0.05	51 - 160 days, 12.40-25.32 kg	"	"
" " "	0.66±0.01 - 0.77±0.02[#]	Birth - maturity	Fourie, Kirton & Jury	(1970)
" " "	0.62 - 0.75 [†]	25 - 150 days	Prud'hon	(1976)
" " "	0.72		Tulloh	(1963)
Carcass or side weight	0.68		Tulloh	(1963)
" " " "	0.64±0.03	13.5 - 35.5 kg	Seebeck	(1966)
" " " "	0.63±0.014-0.77±0.018	Birth - maturity	Fourie *et al*	(1970)
" " " "	0.50	Oxford × 31-65 kg, Dorset × 30-55 kg	Wilson	(1975)
" " " "	0.43±0.17 - 0.67±0.16	15-40 kg, 3 nutritional treatments	Murray & Slezacek	(1976)
Muscle + bone weight	0.72±0.02	2.8 - 99 kg	Elsley, Macdonald & Fowler	(1964)
" " " "	0.73±0.012-0.83±0.013	Birth - maturity	Fourie *et al*	(1970)
" " " "	0.77	Oxford × 31-65 kg, Dorset × 30-55 kg	Wilson	(1975)

[#] includes carcass bone, skull, jaw and feet bones [†] long bones

((Wilson, 1975; Murray and Slezacek, 1976). McClelland *et al* (1976) also found that % lean in the carcass decreased as the animal matured.

Allometric coefficients were greater than 1.0 for the relationship between dissectible lean and lean plus bone weight, a result which indicates an increasing ratio of lean to bone in the carcass.

The allometric coefficients calculated for fat and bone tissues apparently show greater variation between experiments than do those for lean tissue. This variation may be explained in terms of the effect of nutrition on the rate of fat deposition, Elsley, McDonald and Fowler (1964), which may also affect fat deposition in the bone and thus increase the variability of bone weight. Estimates of the 'goodness of fit' of the allometric equation are always highest for dissectible lean tissue (Tulloh, 1963; Elsley *et al*, 1964; Seebeck, 1966; and Bénévent, 1971).

2.2.2 Fat partition between depots

The literature does not give a clear picture of the relative growth of the fat depots of sheep. This may be partly due to the differences between researchers in the definition of the depots, the standards of dissection and the breeds, nutritional treatments and period of growth studied.

The weights of dissectible fat recorded in each depot during growth have been presented by Fourie *et al* (1970), Vezinhet and Prud'hon (1975) and Warren (1976). The new-born lamb contained only small amounts of dissectible fat (e.g. less than 200 g in a 4 kg lamb) and the subcutaneous fat depot was relatively unimportant and

contained less than 14% of total fat. During early post-natal growth subcutaneous fat was deposited rapidly until it reached a value of approximately 30% of total fat at 18 days, Warren (1976), or 25 days, Vezinhet and Prud'hon (1975). At maturity the subcutaneous fat depot represented about 38% of total fat (Fourie *et al*, 1970; Warren, 1976). The patterns of development of the intermuscular and internal fat depots were not so clearly defined. However, intermuscular fat constituted approximately 60% of total fat at birth declining to 36% at maturity, while internal fat represented between 20% and 25% of total fat throughout growth.

Allometric coefficients for the growth of fat depots relative to a number of independent variates are summarised in Table 2.4. In all cases the relative rates of deposition of the subcutaneous fat were higher than those for intermuscular fat. Vezinhet and Prud'hon (1975) reported that the subcutaneous fat depot showed a diphasic growth pattern relative to total fat with an extremely rapid growth rate in early life. Pàlsson and Vergés (1952) contend that the internal fat depots are relatively earlier maturing than the external (particularly subcutaneous) depots. This theory is not entirely supported by the results shown in Table 2.4 in which the rates of growth of KKCF relative to side weight, Murray and Slezacek (1976), and of omental fat relative to starved body weight, Kirton *et al* (1972), and total fat weight, Vezinhet and Prud'hon (1975), were shown to be similar to those of the subcutaneous fat depots. Vezinhet and Prud'hon (1975) reported a low-average diphasic growth pattern for perirenal fat relative to total fat and thus variability in the results of different experiments

Table 2.4 Allometric coefficients (b) for the relative growth of fat depots

Independent variate	Dependent variate	Breed	b	Comments	Author(s)
Empty body weight	Internal	Mérino d'Arles	1.73	Animals following a defined	Bénévent (1971)
" " "	Mesenteric	"	1.94	growth curve.	" "
" " "	Omental	"	3.37	Slaughter at birth, 12 and	" "
" " "	Intermuscular	"	3.03	25 days, 4.13, 6.20 and	" "
" " "	Subcutaneous	"	5.76	9.65 kg	" "
Starved body weight	Channel	Average values	1.27	212 animals slaughtered at	Kirton, Fourie & Jury (1972)
" " "	Kidney	of the	1.42	birth, 1, 6, 11, 16, 25,	" " " "
" " "	Internal	Southdown,	1.60	41, 80 weeks and at	" " " "
" " "	Omental	Romney and	2.21	maturity	" " " "
" " "	Intermuscular	their cross.	1.35	Weight range 3.6-58 kg	" " " "
" " "	Subcutaneous		2.22		" " " "
Jointed side weight	Intermuscular	Dorset Horn ×	1.32	57 animals slaughtered at	Seebeck (1966)
" " "	Subcutaneous	and Merino	1.58	13.5, 19.0, 24.5, 30.0, 35.5 kg	" "

Table 2.4 continued Allometric coefficients (b) for the relative growth of fat depots

Independent variate	Dependent variate	Breed	b	Comments	Author(s)
Carcass weight	Perinephric	Average of the	1.34	See Kirton *et al* (1972)	Fourie, Kirton & Jury (1970)
" "	Intermuscular	Southdown,	1.28		" " " " "
" "	Subcutaneous	Romney and	1.79		" " " " "
		their cross			
Side weight	KKCF	Dorset Horn	1.61	Three nutritional treatments.	Murray & Slezacek (1976)
" "	Intermuscular	cross	1.41	Weight range 15 - 40 kg	" " " "
" "	Subcutaneous		1.63		" " " "
Muscle + bone weight	Intermuscular	Suffolk	1.82	Slaughter age 0-43 weeks	Elsley, MacDonald & Fowler (1964)
" " " "	Subcutaneous	cross	2.15	Weight range 2.8 - 91 kg	" " " " "

Table 2.4 continued Allometric coefficients (b) for the relative growth of fat depots

Independent variate	Dependent variate	Breed	b	Comments	Author(s)
Total fat weight	Perirenal	Merino d'Arles	0.59	20 lambs, 60-750 g total fat	Vezinhet & Prud'hon (1975)
" " "	Perirenal		0.91	79 lambs, 750-6,000 g	" " " "
" " "	Pelvic		0.70	8 females, 60-750 g	" " " "
" " "	Pelvic		0.52	37 females, 750-6,900 g	" " " "
" " "	Pelvic		0.59	54 males, 60-5,000 g	" " " "
" " "	Mesenteric		0.73	20 lambs, 60-750 g	" " " "
" " "	Omental		1.17	99 lambs, 60-6,000 g	" " " "
" " "	Intermuscular		1.00	99 lambs, 60-6,000 g	" " " "
" " "	Subcutaneous		2.04	20 lambs, 60-750 g	" " " "
" " "	Subcutaneous		1.04	79 lambs, 750-6,000 g	" " " "

Table 2.4 continued Allometric coefficients (b) for the relative growth of fat depots

Independent variate	Dependent variate	Breed	b	Comments	Author(s)
Total fat weight	Perirenal	Average of Romanov,	0.82	80 lambs slaughtered at	Prud'hon (1976)
" " "	Pelvic	Romanov × Merino,	0.77	25, 50, 100 and 150	" "
" " "	Mesenteric	Merino d'Arles,	0.88	days of age.	" "
" " "	Omental	Berrichon du Cher,	1.09		" "
" " "	Intermuscular	Berrichon × Merino	0.91		" "
" " "	Subcutaneous		1.18		" "
Total Chemical fat	Omental	Romney, Dorset Horn,	1.33	195 lambs slaughtered	Geenty, Clarke & Jury (1979)
" " "	Kidney	Corriedale and all	1.02	between 3 and 48 weeks.	" " "
" " "	Carcass	two-way crosses	0.97	Liveweight range 5-40 kg	" " "
Total Chemical fat	Omental		1.18		" " "
and slaughter age	Kidney		1.31		" " "
	Carcass		0.97		" " "

may be related to differences in the period of growth studied. Prud'hon (1976) has suggested that the deposition of omental fat is related to rumen development and Vezinhet, Noughes and Vigneron (1976) consider that this depot may have an important metabolic role in the synthesis of fatty acids. Geenty, Clarke and Jury (1979) found that an increase in liveweight growth rate was associated with a decreased rate of growth of omental fat relative to total chemical fat (carcass + omental + kidney fat) and increased rates of development in the kidney and subcutaneous depots. These results suggest a need to clarify the relationships between metabolic functions and growth patterns.

Studies of intramuscular fat in sheep are rare. However, Pryor and Warren (1973) reported fat contents in the muscle ranging from 2.35% to 7.97% of wet muscle weight. Little and Sandland (1975) found that as total fat increased from 1 kg to 10 kg in Merino wether lambs, so the proportion of total fat in the intramuscular fat depot declined linearly from 15% to 6%.

2.2.3 Breed differences in tissue growth

Breed comparisons of serially slaughtered pasture fed lambs have been reported by Seebeck (1966) and Fourie *et al* (1970). For lambs slaughtered between 13.5 kg and 35.5 kg Seebeck (1966) found no significant effect of breed upon the rate of growth of carcass tissues relative to side weight. At any given side weight the pure-bred Merino produced a significantly greater weight of lean and lower weights of fat and bone than the Dorset Horn × (Border Leicester × Merino). The breeds did not differ significantly for weight of intermuscular fat but the Merino carcass contained a

significantly lower proportion of subcutaneous fat ($P < 0.05$) indicating a higher ratio of subcutaneous:intermuscular fat in the Dorset Horn × (Border Leicester × Merino).

Fourie *et al* (1970) reported that the rate of muscle and bone growth relative to carcass weight was significantly higher in the Romney than in Southdown and Southdown × Romney lambs slaughtered between birth and maturity (approximate weight range 4 - 60 kg). The rate of fat deposition relative to carcass weight was not significantly affected by breed. However the rates of body fat (carcass fat + internal fat) deposition relative to starved liveweight and carcass fat deposition relative to muscle plus bone weight were significantly ($P < 0.05$) greater in the Southdown and Southdown × Romney than in the pure Romney. This result is an example of the choice of independent variate affecting conclusions about breed differences in tissue growth patterns.

For housed lambs slaughtered at liveweight between 30-65 kg Wilson (1975) reported that the progeny of a Dorset Down sire deposited fat relative to carcass or lean weight at a greater rate than the progeny of another Dorset Down sire and an Oxford sire. The opposite effect was seen for lean growth relative to carcass weight. The intercept for the relationship between $\log_{10}$ lean weight and $\log_{10}$ bone weight was lower ($P < 0.05$) for the progeny of the Oxford sire than for the progeny of the Dorset Down sires. Oxford cross lambs tended to deposit lean relative to bone at a faster rate than Dorset Down cross lambs ($P < 0.10$).

Knapman (1976) studied growth in Southdown, Suffolk and Cotswold cross lambs slaughtered over the range of 40-70% of mature

size, i.e. at liveweights of 27-48 kg for the Southdown and 34-57 kg for the Suffolk and Cotswold crosses. At 34 kg liveweight dissectible lean tissue constituted 25% of the liveweight in all breed crosses and 22% of each unit of subsequent liveweight gain. The Southdown cross tended to produce a higher weight of lean at constant lean plus bone weight. At a constant carcass weight of 16 kg the Southdown cross produced 4% less lean than the other two crosses and the rate of lean growth was 4 percentage units greater in the Cotswold. Breeds differed in bone weight by approximately 1% of carcass weight in the order Southdown < Suffolk < Cotswold. Breed differences in weight and rates of deposition of internal fat (channel plus thoracic depots) were negligible but the Southdown cross tended to contain more intermuscular and subcutaneous fats and have greater rates of deposition relative to carcass weight than the Suffolk and Cotswold crosses.

In general there is an indication within these experiments that breeds of low mature weight tend to deposit fat relative to carcass or muscle weight at a faster rate than breeds of larger mature size. The reverse trend appears to be true for the rates of muscle and bone growth relative to carcass weight. However this may be a fortuitous result of the choice of limited numbers of breeds which differ fairly widely in mature size. Seebeck (1966) could not demonstrate breed differences in tissue growth patterns and Wilson (1975) has shown differences between sires of the same breed. Berg, Andersen and Liboriussen (1978) found no significant differences between breeds of cattle for the allometric coefficients of fat deposition relative to several size dimensions. However the fattest

breed (Hereford) tended to have a higher coefficient and the leanest breed (Blonde d'Aquitaine) tended to have a lower coefficient than the average over all breeds. The reverse was found for lean tissue growth.

McClelland, Bonaiti and Taylor (1976) found that the Southdown and Oxford Down which had expected mature sizes of 60.2 kg and 110.5 kg respectively, reached slaughter at approximately 55% of expected mature size at 186 and 198 days of age respectively when fed a complete diet *ad-libitum*. At equal degree of maturity the breeds did not differ for percentage carcass lean in the fleece-free empty body but the Oxford contained a higher percentage of carcass fat. However, this result must be treated with caution since some difficulty was experienced during the rearing stages of the Southdown lambs.

2.2.4 Sex differences in tissue growth

In a comparison of the sexes at equal age (range = 0 - 160 days) and empty body weight (range = 4 - 25 kg) Bénévent (1971) found no significant differences between males and females in either intercept or slope for lean tissue growth relative to empty body weight. However males yielded higher weights of bone and lower weights of fat particularly at empty body weights greater than 9 kg. Over a range of starved liveweights from birth to maturity (4.3 - 55.8 kg) Fourie *et al* (1970) demonstrated significantly higher allometric coefficients for the growth of muscle ($P < 0.05$) and bone ($P < 0.001$) in males than in females, whilst females deposited fatty tissue more rapidly ($P < 0.001$).

At any given side weight males contained a higher proportion of bone and muscle and a lower proportion of fat than females,

Seebeck (1966), Fourie *et al* (1970) and wether lambs were intermediate between rams and ewes although not significantly different ($P < 0.05$) from the males, Seebeck (1966). Seebeck (1966) did not report sex differences in allometric coefficients but Fourie *et al* (1970) found that the rate of fat deposition relative to carcass weight was greatest in females and that the relative growth rates of muscle and bone were greatest in males.

Females showed significantly greater ($P < 0.01$) rates of muscle and fat deposition relative to muscle + bone weight but lower rates of bone growth than males, (Fourie *et al*, 1970). Wilson (1975) found that although females tended to deposit fat at a faster rate than wethers relative to muscle plus bone weight, the difference in the allometric coefficient did not reach significance at the 5% level.

At equal stages of maturity sex differences in muscle and chemical fat (expressed as a percentage of fleece-free empty body) were not evident but males yielded a significantly higher ($P < 0.001$) proportion of bone. When dissectible lean, fat and bone were expressed as a percentage of carcass weight no significant differences due to sex were found in equally mature lambs (McClelland *et al*, 1976).

2.3 MUSCLE WEIGHT DISTRIBUTION

2.3.1 Introduction

Some joints of the lamb carcass are more highly valued by consumers than others. Joints which can be roasted or grilled are preferred to joints which require stewing or slow cooking. Factors such as presentation, the area of the lean meat, its texture, colour and tenderness together with the quantity and distribution of the fat throughout the joint will affect consumer preference. Consequently

variation in muscle distribution will affect carcass value. This factor has been recognised by generations of animal breeders who have selected animals on the basis of conformation in an attempt to improve the proportion of lean meat in the highly valued hind-quarters of the animal. Recent research has been directed at developing an understanding of the differential growth of the musculature. Effort has also been made to determine the factors which affect muscle distribution in the carcass and to evaluate the extent to which these factors can be exploited to improve carcass value.

2.3.2 Patterns of muscle development

Two distinct types of dissection have been used in the study of muscle distribution. The first of these is the dissection of lean tissue from standard joints. The method has the advantage that the information obtained is directly relevant to the problems of the industry. However, jointing techniques are not uniform throughout the world and comparison of the results of different experiments is often difficult. Also the joints may contain muscles, or parts of muscles with different functions or growth patterns and consequently the interpretation of the data in biological terms is difficult. Butterfield (1963a) used an anatomical approach with dissection of individual muscles from serially slaughtered cattle. Muscles were classified as early, average or late in development if they constituted a decreasing, constant or increasing proportion of total muscle mass respectively. Butterfield and Berg (1966a) used the allometric equation to analyse differential muscle growth. Muscles were said to have low, average or high impetus for growth, where the

allometric coefficient (b) was smaller than, equal to or greater than one respectively. Muscles were classified according to their impetus for growth in arbitrarily assigned growth phases. Furthermore, muscles were grouped according to anatomical location to allow interpretation in either functional or commercial terms.

Butterfield (1963b) concluded that the major portion of differential muscle growth in cattle occurs before 240 days of age. Butterfield and Johnson (1968) studied individual muscle growth in cattle over five phases of growth defined by age. From birth to 84 days of age 21 muscles (41.5% of total muscle mass) had allometric coefficients which were significantly different from one. For growth phases beyond this age only 8 or less muscles (less than 10% of total muscle weight) showed differential growth.

In sheep, Lohse, Moss and Butterfield (1971) estimated allometric coefficients for individual muscles over different phases of muscle growth, defined as multiples of the lowest total muscle weight recorded. Jury, Fourie and Kirton (1977) tested for non-linearity in the allometric equation and made classifications accordingly. The pattern of growth for the standard muscle groups are summarised in Table 2.5. Growth patterns for standard muscle groups in cattle, Butterfield and Berg (1966b), are presented for comparison.

Muscles of the proximal pelvic limb showed a high, monophasic growth pattern (b = 1.08), Lohse *et al* (1971) whilst Jury *et al* (1977) found that the allometric coefficient declined from a value of 1.07 at 1,000 g half carcass muscle to one of 1.01 at 6,000 g in males (1.09 and 0.92 in females). Other workers present low values for the allometric coefficient relating muscle in the leg to half carcass

Table 2.5 Growth patterns of standard muscle groups of sheep and cattle

Muscle group	Lohse *et al* (1971)#	Jury *et al* (1977)#	Butterfield and Berg (1966b)†
1. Proximal pelvic limb	High	High - decreasing	High - average or low
2. Distal pelvic limb	Low	Low - decreasing	Low
3. Around spinal column	High - average	High - decreasing	Average
4. Abdominal wall	High	High	High - average or high
5. Proximal thoracic limb	Average - low	Low	Low - average
6. Distal thoracic limb	Low	Low	Low - average or low
7. Thorax to thoracic limb	Average	Low - increasing	High
8. Neck to thoracic limb	Average - low	Average	Average - high
9. Neck and thorax	Low - average	Low - increasing	Low - average

sheep

† cattle

muscle, Seebeck (1968), Jackson (1969) and Prud'hon (1976). However the leg joint in these reports also includes the muscles of the distal pelvic limb.

Lohse *et al* (1971) and Jury *et al* (1977) agree that early post-natal growth of the muscles surrounding the spinal column is at a somewhat higher rate than total muscle declining to an average (Lohse *et al*, 1971) or below average (Jury *et al*, 1977) pattern at later stages. Prud'hon (1976) presents values in the range 0.96 to 1.09 for the muscle group although statistical tests are not presented. Seebeck (1968) reported a value of 1.18 for muscle in the loin and flank.

Muscles of the abdominal wall grow at a high rate relative to total muscle, Lohse *et al* (1971), Prud'hon (1976), Jury *et al* (1977). Muscles of the proximal and distal thoracic limb become a declining proportion of total muscle with increasing total muscle weight, Lohse *et al* (1971), Jury *et al* (1977), which is in agreement with values given for the shoulder joint, Seebeck (1968), Prud'hon (1976).

Allometric coefficients for the muscles joining the thoracic limb to the neck and thorax are close to 1.0, Lohse *et al* (1971) and Jury *et al* (1977), whilst muscles of the neck and thorax show a low-average pattern of growth which is in agreement with values given for these joints by Seebeck (1968) and Prud'hon (1976).

Taylor, Mason and McClelland (1980) examined the development of 12 individual muscles comprising 41% of total muscle between 40 and 76% of mature size. The majority of muscles examined showed an initial decrease relative to total muscle weight as the animal

increased in maturity and showed little change thereafter. However a few muscles continued to decline as a porportion of the whole although the final conclusion was one of fairly constant muscle distribution after an initial phase of differential growth.

In practice the small changes in muscle distribution which occur over the normal range of commercial slaughter weights are unlikely to be important enough to merit consideration in the planning of lamb production systems (Jury *et al*, 1977). Similar conclusions were drawn by Kempster, Cuthbertson and Smith (1976) in a study of lean distribution in steer carcasses.

2.3.3 Breed differences in muscle distribution

Breed differences in the allometric coefficients relating muscles of the distal pelvic limb, the spinal column, distal thoracic limb and the junction of the thoracic limb and thorax to total muscle weight were reported by Jury *et al* (1977). Prud'hon (1976) also reported different allometric coefficients in different breeds but did not present statistical tests. However breed differences in muscle distribution (muscle group expressed as a percentage of total muscle) at a constant total muscle weight were small, Jury *et al* (1971), and were considered to be of little economic importance. Seebeck (1968) found that the Merino contained a significantly higher ($P < 0.05$) proportion of total side muscle in the neck joint and a lower proportion in the thorax than the Dorset Horn cross Border Leicester - Merino.

In a study of commercial lamb carcasses in British abattoirs Kempster, Cuthbertson and Smith (1977) reported a range in breed means for the percentage of total lean in the higher priced cuts of

54.7% to 57.3%. The carcasses were produced in a wide range of environments and it is likely that this range in percentage lean in the higher-priced cuts is representative of the maximum variation occurring in practice. Within the breed types studied a number of breeds did not differ significantly for this trait.

Croston, Jones and Kempster (1979) reported that lambs sired by the Border Leicester contained 53.5% of total lean in the higher-priced joints. Seven other terminal sire breeds studied contained from 54.5% to 55.4% of total lean in the higher-priced joints and did not differ significantly from one another when compared at a constant level of subcutaneous fat in the carcass.

Where breeds differ widely in expected mature size comparisons of their muscle distribution at constant muscle weight may be influenced by differences in stage of maturity. When considered at the same stage of maturity 12 individual muscles from the higher-priced joints comprised 40.8, 43.4, 40.5 and 39.8% of total muscle weight in the Soay, Southdown, Finnish Landrace and Oxford Down respectively (Taylor *et al*, 1980). Prud'hon (1976) reported that the Romanov and Merino's d'Arles contained up to 5% less of total muscle in the thigh than the Berrichon du Cher at equal stage of maturity. Kempster *et al* (1976) and Bergström (1978) have also suggested that the lean tissue distribution of cattle breeds may vary even when comparisons are made between breeds of similar mature size.

2.3.4 The effect of sex on muscle distribution

Male and female lambs differed in allometric coefficients for many muscles throughout the body, Lohse (1973), Jury *et al* (1977),

but weight differences were particularly noticeable for the individual muscles of the neck which are responsible for crest formation in the male. Seebeck (1968) found a non-significant trend for males to have a greater proportion of total muscle in the neck joint than females. Taylor *et al* (1980) found that at equal degree of maturity female lambs had a higher proportion of total muscle in the prime joints (particularly the gigot) than males. Lohse (1973) reported that the growth coefficients of the total muscle of the proximal hind-limb declined earlier in ewe lambs than in rams. However, Jury *et al* (1977) found the reverse to this and reported a difference of 1.9% of a total muscle weight of 6,000 g in favour of the females.

2.3.5 The effect of growth rate on muscle distribution

Studies of muscle distribution at constant muscle weight in sheep have shown small, but commercially unimportant differences due to rate of liveweight growth, Boccard and Dumont (1973) and Murray and Slezacek (1975). Litter size had no effect upon the muscle distribution of lambs at equal stages of maturity (Taylor *et al*, 1980).

2.4 FAT DISTRIBUTION

2.4.1 Relative growth of subcutaneous fat and intermuscular fat in standard joints

The allometric coefficients for subcutaneous fat and intermuscular fat in standard joints relative to the total weight of each tissue in the carcass reported by Seebeck (1968) and Thompson, Atkins and Gilmour (1979) are shown in Table 2.6. Both experiments were consistent in showing that as the total weight of each fat depot in the carcass increased the proportion of fat in the limbs

Table 2.6 Allometric coefficients for subcutaneous fat, intermuscular fat and muscle weight in standard carcass joints relative to the total weight of the respective tissue in the carcass

	Subcutaneous fat	Intermuscular fat	Muscle
A[#]			
Neck	1.17±0.10	1.53±0.09	1.19±0.04
Thorax	1.05±0.04	0.94±0.03	0.90±0.02
Loin + Flank	1.17±0.04	1.15±0.05	1.18±0.03
Shoulder	0.90±0.05	0.95±0.07	0.98±0.02
Leg	0.87±0.04	0.84±0.06	0.93±0.02
B[#]			
Hindlimb	0.94±0.02	0.78±0.03	0.98±0.02
Loin	1.05±0.04	0.82±0.09	0.93±0.05
Thorax	1.04±0.02	1.00±0.02	1.09±0.02
Forelimb	0.89±0.03	0.54±0.05	0.93±0.02
Flank	1.05±0.03	1.58±0.06	0.95±0.05

[#] Results presented by A. Seebeck (1968) and B. Thompson, Atkins and Gilmour (1979).

decreased and the proportion in the trunk increased or remained constant. This disto-proximal growth pattern was similar to that found for muscle (Table 2.6).

2.4.2 The effect of breed and sex

Thompson *et al* (1979) found no differences between breeds or sexes for subcutaneous and intermuscular fat distribution. Gaili (1978) reported a significant effect of breed upon intermuscular fat distribution. However, the largest difference found was 68 g less fat in the neck and thorax of the Hampshire than in the Dorset Horn and Clun when compared at 42 kg liveweight. This difference represented 11% of the weight of intermuscular fat in the neck and thorax and adjustment to a constant weight of intermuscular fat in the side reduced it to 34 g. Sex did not affect intermuscular fat distribution.

Seebeck (1968) reported a small but generally non-significant effect of sex upon the distribution of both subcutaneous and intermuscular fat after adjustment to constant weight of depot fat in the side. Significant breed differences ($P < 0.01$) rarely exceeded 10% of the weight of fat in the joint.

2.5 THE HERITABILITY OF LIVEWEIGHT GROWTH AND CARCASS COMPOSITION

2.5.1 Heritability estimates of liveweight growth

Published heritability estimates for birthweight, weaning weight and average daily gains are summarised in Tables 2.7 to 2.10. Heritability estimates for birthweight and weaning weight range from 0 to 0.45 with pooled values (weighted by the inverse of the variance of the estimates) of 0.17 and 0.15 respectively. The heritability of liveweights and growth rates may vary with the age of lamb,

Table 2.7 Summary of paternal half-sib estimates of heritability of birth weight

Breed	Comment	Heritability	Author(s)
1. Hampshire cross	Twins, permanent pasture	0.03±0.16	Vogt, Carter & McClure (1967)
2. Suffolk cross	Lowland pasture	0.08±0.05	Bichard & Yalcin (1964)
3. Scandinavian	Twins, transhumance	0.09±0.05	Gjedrem (1967)
4. Corriedale & Down types		0.10	Butcher, Dunbar & Welch (1964)
5. Down cross		0.10±0.07	Thrift, Whiteman & Kratzer (1973)
6. Scandinavian	Singles & twins, transhumance	0.12±0.05	Gjedrem (1967)
7. Southdown		0.12±0.06	Thrift, Dutt & Woolfolk (1971)
8. Barki	Singles, desert	0.15±0.14	Galal (1968)
9. Longwool crossbred	High altitude range	0.19±0.07	Osman & Bradford (1965)
10. Merinos d'Arles	Transhumance	0.24±0.05	Bonaiti, Flamant, Prud'hon, Berny & Devignes (1976)
11. Hampshire cross	Singles, permanent pasture	0.31±0.20	Vogt *et al* (1967)

Table 2.7 continued Summary of paternal half-sib estimates of heritability of birth weight

Breed	Comment	Heritability	Author(s)
12. Cross-bred	High altitude range	0.31±0.10	Ercanbrack & Price (1972)
Rambouillet		0.26±0.13	" " "
Targhee		0.30±0.10	" " "
Columbia		0.12±0.11	" " "
13. Scandinavian	Singles, transhumance	0.33±0.16	Gjedrem (1967)
14. Down, Merino, coarsewool	Pasture with ad-lib hay	0.35±0.11	Olson, Dickerson & Glimp (1976)
15. Rambouillet	Males	0.30±0.16	Vesely & Robison (1970)
"	Females	0.39±0.16	" " "
Romnelet	Males	0.22±0.15	" " "
"	Females	0.40±0.18	" " "
16. Longwool crossbred	Irrigated pasture	0.45±0.17	Osman & Bradford (1965)

Pooled estimate* = 0.17, Down cross (1,2,5,7,11) = 0.10
Merino and range sheep (9,10,12,14,15) = 0.25

*Weighted by the inverse of the variance of the estimate.

Table 2.8 Summary of paternal half-sib estimates of the heritability of weaning weight

Breed	Comment	Heritability	Author(s)
1. Corriedale & Down		0	Butcher, Dunbar & Welch (1964)
2. Scandinavian	150 days, twins, transhumance	0.04±0.03	Gjedrem (1967)
3. Rambouillet	126 days, males	0.07±0.13	Vesely & Robison (1970)
"	" " females	0.06±0.12	" " "
Romnelet	" " males	-0.10±0.11	" " "
"	" " females	0.12±0.14	" " "
4. Suffolk cross	105 days, lowland pasture	0.10±0.06	Bichard & Yalcin (1964)
5. Down cross	70 days,	0.10±0.07	Thrift, Whiteman & Kratzer (1973)
6. Rambouillet, Columbia, Corriedale & crosses	71 days, range pasture	0.10±0.07	Botkin, Field, Riley, Nolan & Roehrkasse (1969)
7. Hampshire cross	120 days, twins, grass-legume	0.12±0.15	Vogt, Carter & McClure (1967)
8. Southdown	120 days,	0.13±0.06	Thrift, Dutt & Woolfolk (1971)
9. Scandinavian	155 days, 2,301 flocks	0.14±0.01	Eijke (1974)
10. Icelandic	*c.* 134 days, 370 farm × year	0.18±0.02	Jónmundsson (1977)
11. Scandinavian	150 days, transhumance	0.18±0.06	Gjedrem (1967)

Table 2.8 continued Summary of paternal half-sib estimates of the heritability of weaning weight

Breed	Comment	Heritability	Author(s)
12. Merino	85 - 168 days	0.18±0.19	Pattie (1965)
13. Down, Merino & Coarsewool	70 days, pasture + creep	0.18±0.09	Olson, Dickerson & Glimp (1976)
14. Longwool crossbred	120 days, high altitude range	0.19±0.08	Osman & Bradford (1965)
15. Down, Merino & Coarsewool	98 days, pasture + creep	0.21±0.09	Olson *et al* (1976)
16. Scandinavian	150 days, singles	0.26±0.14	Gjedrem (1967)
17. Rambouillet	157 days, range	0.33	Shelton & Campbell (1962)
18. Longwool crossbred	120 days, irrigated pasture	0.40±0.17	Osman & Bradford (1965)
19. Cross-bred	High altitude range,	0.34±0.10	Ercanbrack & Price (1972)
Rambouillet	120 day weight	0.45±0.14	" " "
Targhee		0.16±0.09	" " "
Columbia		0.15±0.11	" " "
20. Hampshire cross	120 days, singles	0.57±0.22	Vogt *et al* (1967)
21. Columbia, Corriedale		0.21±0.09	Botkin (1964)

Pooled estimate = 0.15, Down cross (4,5,7,8,20) = 0.12,
Merino and range sheep (3,6,13,14,18,19,21) = 0.18

Table 2.9 Summary of paternal half-sib estimates of the heritability of average daily gains for periods starting at birth

Range	Heritability	Author(s)
Birth - 112 days	0	Bowman & Hendy (1972)
Birth - 120 days	0.07±0.06	Thrift, Dutt & Woolfolk (1971)
Birth - 70 days	0.09±0.06	Thrift, Whiteman & Katzer (1973)
Birth - 50 lbs	0.10±0.07	Harrington, Brothers & Whiteman (1962)
Birth - 112 days	0.07 to 0.23	Bowman & Broadbent (1966)
Birth - 120 days (twins)	0.13±0.15	Vogt, Carter & McClure (1967)
Birth - 70 days	0.19±0.05	Olson, Dickerson & Glimp (1976)
Birth - 90 days	0.24±0.09	Botkin, Field Riley, Nolan & Roehrkasse (1969)
Birth - slaughter (35-45 kg)	0.26±0.22	Bowman & Hendy (1972)
Birth - 90 lbs	0.35±0.12	Harrington *et al* (1962)
Birth - 120 days (singles)	0.37±0.20	Vogt *et al* (1967)
Birth - 120 days	0.33±0.10	Ercanbrack & Price (1972)
" " "	0.39±0.14	" " "
" " "	0.17±0.09	" " "
" " "	0.14±0.11	" " "

Pooled estimate for growth rates to a fixed age = 0.17

Table 2.10 Summary of paternal half-sib estimates of the heritability of average daily gains for periods not including birth

Trait (Gain between)	Heritability	Author(s)
35 - 155 days	0.13±0.01	Eijke (1974)
100 - 170 days	0.20±0.07	Vesely & Peters (1975)
70 days to 42-44 kg	0.23±0.12	Thrift, Whiteman & Kratzer (1973)
126 - 256 days	0.14±0.14	Vesely & Robison (1970)
"	0.15±0.13	" " "
"	0.27±0.16	" " "
"	0.29±0.17	" " "
10 - 30 days	0.24±0.05	Bonaiti, Flamant, Prud'hon Berny & Desvignes (1976)
14 - 112 days	0.32±0.21	Broadbent & Watson (1967)
98 days to slaughter	0.33±0.10	Olson, Dickerson & Glimp (1976)
50 lb - 90 lb	0.38±0.13	Harrington, Brothers & Whiteman (1962)
56 - 112 days	0.52±0.28	Broadbent & Watson (1967)
120 - 395 days	0.43±0.11	Ercanbrack & Price (1972)
" " "	0.40±0.14	" " "
" " "	0.52±0.12	" " "
" " "	0.58±0.14	" " "

tending to be higher at birth than during suckling. It has been suggested that this is due to variation in maternal milking ability and competition between full sibs (Bichard and Yalcin, 1964; Bowman, 1968; Bonaiti, Flamant, Prud'hon, Berny and Desvignes, 1976). Where a series of pre-weaning liveweights has been recorded, heritability estimates tended to increase towards weaning (Bichard and Yalcin, 1964; Bonaiti *et al*, 1976). However, the heritability of weaning weight has been found to be lower than, Olson, Dickerson and Glimp (1976), equal to, Osman and Bradford (1965) and Thrift, Whiteman and Kratzer (1973), or higher, Gjedrem (1967), than the heritability of birthweight. This is not unexpected because different workers have studied these traits in different populations maintained in different environments with weaning taking place over a wide range of ages. Where different breeds have been recorded in the same environment, trends in the heritability between birth and weaning have not been consistent across breeds (Vesely and Robison, 1970; Ercanbrack and Price, 1972).

The heritability of liveweights and growth rates may increase after weaning (Osman and Bradford, 1972; Vesely and Robison, 1970; Ercanbrack and Price, 1972; Olson *et al*, 1976). However, some exceptions to this trend have been found where nutritional conditions have limited growth (Ercanbrack and Price, 1972). Vesely and Robison (1970) reported that the heritability of liveweight at the end of a 126 day post-weaning concentrate feeding period was not higher than the heritability of birthweight.

Estimates of the heritability of liveweight growth in the Down breeds of the U.K. have generally been low, Bichard and

Yalcin (1964), Bowman and Broadbent (1966), Broadbent and Watson (1967), Bowman and Hendy (1972) and lower than in the range breeds of the U.S.A. (Tables 2.7 and 2.8). Bowman (1968) has suggested that selection for early growth rate in the Down breeds may have reduced the genetic variance for liveweight traits. It is also possible that differences in environmental factors could be involved in reducing heritability estimates in British versus American flocks. Recent studies of M.L.C. Performance Recorded Flock data (P.R. Bampton, personal communication) gave a pooled heritability estimate of eight week weight of 0.16±0.02 which is higher than previously published estimates.

Heritabilities were estimated in two environments by Osman and Bradford (1965). Although no significant differences were found between estimates at two different locations both the phenotypic variance and the heritability estimates were consistently higher in the better environment. Different rearing types afford an opportunity to estimate heritability under different nutritional conditions within the same flock. Heritability estimates were found to be higher in single lambs than in twins, Vogt, Carter and McClure (1967), Gjedrem (1967) and Hallgrimsson (1971) (quoted by Jónmundsson, 1977) although other studies have found no difference (Jónmundsson, 1977; Martin, Sales, Smith and Nicholson, 1980). Early weaning followed by the artificial rearing of Suffolk ram lambs increased heritability estimates of early growth (Owen, Brook, Read, Steane and Hill, 1978).

Sex had no significant effect upon the heritability estimates of body weight, Young, Turner and Dolling (1960),

Pattie (1965) and Vesely and Robison (1970) but selection experiments for weaning weight, Pattie (1965), and postweaning gain, Vesely and Robison (1970), have shown greater response to selection in females than in males. No explanations were given for these results.

There is little evidence concerning the influence of cross-breeding on heritability estimates. In chickens Pirchner and Krosigk (1973) found that the heritability of body weight at 18 weeks was the same in pure- and cross-bred flocks although heritabilities for sexual maturity and egg production were highest in the crossbred. Ercanbrack and Price (1972) presented heritability estimates for weights and gains in Rambouillet, Targhee and Columbia range sheep and in a group of all possible two-way crosses. The pooled estimates of heritability of liveweights for pure breds tended to be lower than those in the crossbred lambs but the heritabilities of gains were the same in both groups.

2.5.2 Heritability of carcass composition

Heritability estimates for a limited number of carcass traits are summarised in Tables 2.11 and 2.12. Percentage lean and fat in the carcass and fat depths had moderate heritability (0.4 - 0.5) but published estimates of the heritability of killing-out percent and eye-muscle area were not in good agreement.

Table 2.11 Summary of paternal half-sib estimates of the heritability of lamb carcass traits at constant liveweight

Trait	Slaughter weight	Heritability	Author(s)
Carcass weight	80-90 lb	0.02	Bowman, Marshall & Broadbent (1968)
" "	35-45 kg	0.11±0.18	Bowman & Hendy (1972)
" "	50 kg	0.33±0.11	Botkin, Field, Riley, Nolan & Roehrkasse (1969)
Carcass weight/ day of age	50 kg	0.35±0.11	Botkin *et al* (1969)
Killing-out %	35 kg	0.16±0.17	Cotterill & Roberts (1976)
" " "	50 kg	0.41±0.12	Botkin *et al* (1969)
% Lean	50 kg	0.40±0.12	Botkin *et al* (1969)
% Fat	" "	0.54±0.13	" " " "
% Bone	" "	0.23±0.09	" " " "
Weight of lean	" "	0.39±0.12	" " " "
Weight of fat	" "	0.44±0.12	" " " "
Weight of bone	" "	0.28±0.10	" " " "
Lean/bone ratio	" "	0.19±0.09	" " " "
Eye-muscle area	35-45 kg	0.14±0.20	Bowman & Hendy (1972)
	50 kg	0.34±0.11	Botkin *et al* (1969)
	80-90 lb	0.53	Bowman *et al* (1968)
Back-fat depth	35 kg	0.37±0.21	Cotterill & Roberts (1976)
	35-45 kg	0.40±0.26	Bowman & Hendy (1972)
	50 kg	0.51±0.13	Botkin *et al* (1969)

Table 2.12 Summary of paternal half-sib estimates of the heritability of lamb carcass traits at constant age

Trait	Heritability	Author(s)
Carcass weight	0.35±0.14	Olson, Dickerson, Crouse & Glimp (1976)
" "	0.53±0.25	Timon (1968)
Killing-out %	0.06±0.11	Olson *et al* (1976)
% Protein	0.51±0.26	Timon (1968)
% Ether extract	0.50±0.26	" "
% Bone	0.32±0.22	" "
% Bone	0.04±0.11	Olson *et al* (1976)
Weight of bone	0.43±0.14	" " " "
Lean/bone ratio	0.36±0.23	Timon (1968)
Eye-muscle area	0.12	Smith, Kemp, Moody & Cundiff (1968)
" " "	0.56±0.26	Timon (1968)
Back-fat depth	0.27	Smith *et al* (1968)
" " "	0.28±0.13	Olson *et al* (1976)

CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

An experimental flock of ewes was set up at the Animal Breeding Research Organisation's Cold Norton Farm, Staffordshire, in the autumn of 1971. The objectives of the experimental work were :

1) to compare a traditional crossbred ewe type (Border Leicester × Scottish Blackface) with the cross of a new synthetic breed (ABRO Dam Line × Scottish Blackface).
2) to compare six terminal sire breeds in crossbred lamb production.
3) to provide data for the estimation of genetic parameters for growth and carcass composition.

The following sections describe the composition and management of the flock, slaughter procedures, dissection techniques and the statistical methods employed in the analysis of the data.

3.2 EXPERIMENTAL MATERIAL

3.2.1 Fixed Slaughter weight Trial

Records for lamb growth to 12 weeks of age were available from 1972 - 1976, age at slaughter and carcass weight data from 1972 - 1975, and carcass dissection data from 1973 - 1975 inclusive.

Both crossbred ewe types were produced under contract on an Ayrshire hill farm using Scottish Blackface ewes of the Newton Stewart strain. Border Leicester rams were purchased by the farmer and ABRO Dam Line rams were drawn from the Skedsbush flock whose composition is given by Smith, King, Nicholson, Wolf, Bampton (1979) as Finnish

Landrace (47%), East Friesland (24%), Border Leicester (17%) and Dorset Horn (12%). About 3-4 rams of each sire breed were used each year. Approximately 100 ewe lambs/crossbred type/year were transferred to the experimental flock at 16-18 weeks of age and were maintained there until the end of their third year. Thus flock size and age structure developed from some 200 yearlings in 1972 to a flock size of about 600 in 1973 and subsequent years, with approximately equal numbers of ewes in the 1, 2 and 3 year age groups. All ewe lambs were exposed to the ram.

Three British breeds - Suffolk, Oxford Down, and Dorset Down - and three foreign breeds - Oldenburg, Ile de France and Texel - were represented by 2 rams/breed in 1972, 3 rams/breed in 1973 and 4 rams/breed in 1974 and subsequent years. Sires were used for one year only. The Oxford rams came from the ABRO Oxford control flock which was created in 1970 from some 12 Oxford flocks. Rams of the other British breeds were recruited by the MLC from different sources, while the foreign breeds were obtained from the few breeders who had imported these breeds. In all cases, representative, average rams which were unrelated (if possible) were sought. The Texel rams were derived from Dutch strains.

Mating took place in paddocks between mid-October and mid-November each year. Approximately 8-10 ewes of each crossbred type were randomly allocated to every sire. The ewes were observed twice a day and a date of tupping was recorded for newly marked ewes. A three colour raddle system allowed the identification of ewes returning to service. Scottish Blackface rams were used as chasers, being introduced 1 week after the end of the formal mating period.

Management during the first 15 weeks of pregnancy was directed towards the prevention of an appreciable loss of ewe body condition. Where grazing did not satisfy this requirement supplementary hay was fed. As the flock size was too large to allow the ewes to be run in a single group they were managed according to age group, a practice which did not differentially affect the two breeds but did allow for preferential treatment of the ewe lambs. During the final six weeks of pregnancy the ewes were run in three groups, the first containing all ewes mated during the first 10 days of tupping, and so on. Supplementary feeding of concentrates was introduced at 0.1 kg/head/day when the first ewe in each group was within 6 weeks of its estimated date of lambing, and rose to 0.3 kg/head/day 3 weeks before lambing and to 0.7 kg/head/day in the final week.

Management at lambing sought to reduce peri-natal mortality and to form a strong ewe-lamb bond with a minimum of mis-mothering. Ewes were housed at night and during bad weather and were regularly checked for lambing. At night the ewe and her newborn litter were confined to small pens. Ewes lambing in the field were brought indoors and penned. Ewes with poor milk supply or small, weakly lambs were housed for up to 3-4 days. Fostering and artificial rearing were practised only in extreme cases and generally a ewe with a large litter was required to rear the litter unaided.

Birthweight was measured to the nearest 0.1 kg when the birthcoat had dried, the navel was treated with iodine, tail docking and castration were carried out using the rubber ring technique, the lamb was tagged in both ears, and litter size, sex and ewe and lamb identities were recorded. Any lamb born outside the range of 145±5 days from its dam's recorded date of mating was taken as non-pedigree.

The ewes and lambs were set stocked on grass/clover mixtures with concentrate feeding to the ewe until lactation was well established and grass growth was satisfactory. The ewes were managed in groups according to litter size. To ease the recording of later weights, the lambs were colour marked on the nape of the neck according to their week of birth. Lambs were weighed weekly to the nearest 0.5 kg at 4, 8, 12 and 16 weeks of age plus 0-6 days. Rearing-type, i.e. litter size, was recorded at 8 weeks.

In 1972-1973 lambs were weaned at 12 weeks or, if they were close to their allocated slaughter weights, they remained with their dams until 15 weeks or slaughter, whichever came first. In later years weaning was delayed until 16 weeks and throughout the experiment no lamb was slaughtered before 12 weeks of age.

After weaning the ewes were kept at a stocking rate which prevented them from becoming over-fat. The lambs were given the best grass available and were slaughtered when they reached a randomly allocated slaughter weight of 35 kg or 40 kg. Lambs not reaching their required weight were slaughtered before Christmas.

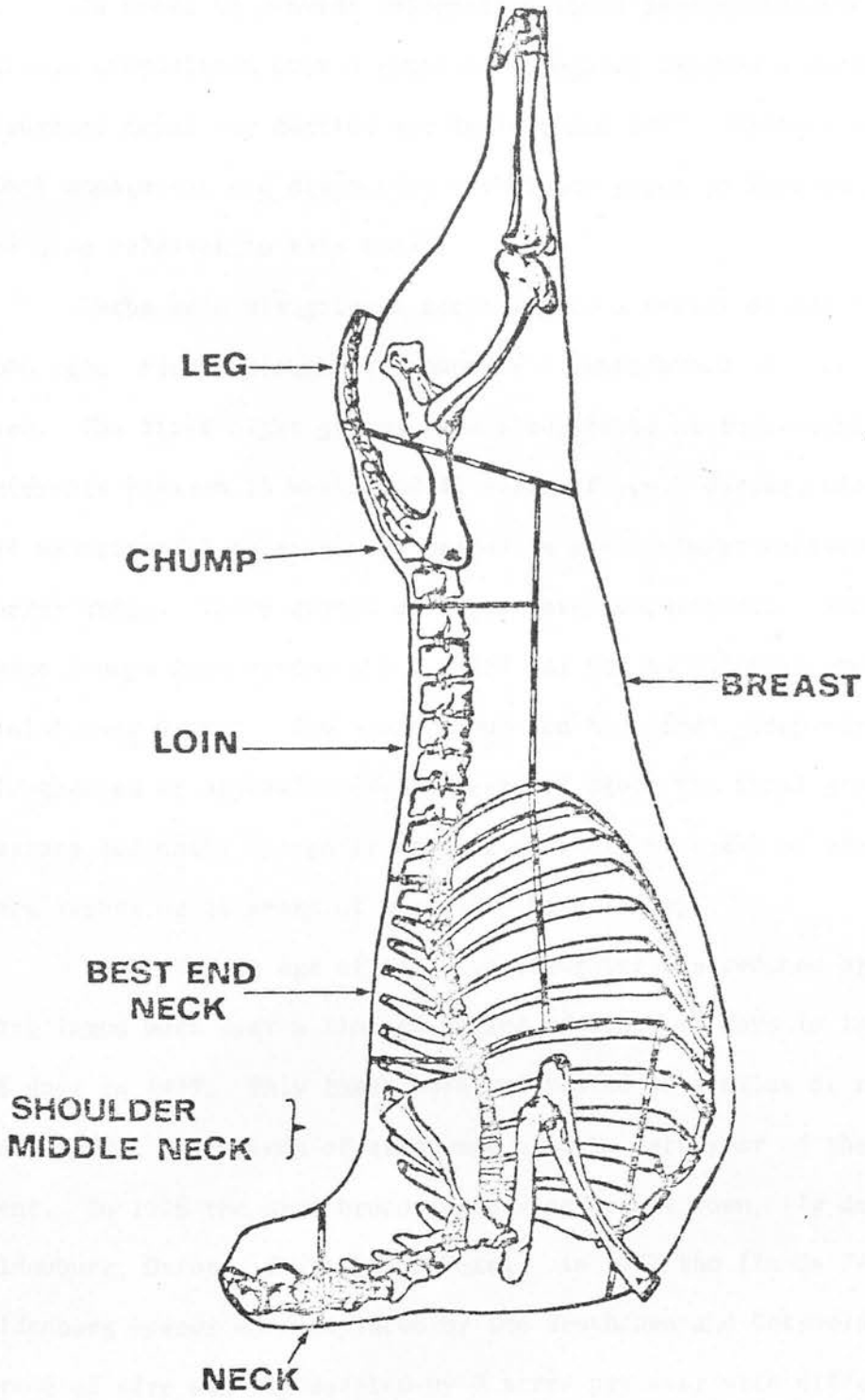
Lambs approaching slaughter weight were weighed weekly and if within 0.5 kg of the required slaughter weight were sent to a local abattoir on the following day without any pre-slaughter fasting regime. Slaughter was by an incision of the neck following electrical stunning, and the carcass was prepared following normal commercial practice without recording details of the non-carcass components. After hanging for 24 hours cold carcass weights were recorded and carcasses which were assigned for dissection underwent the standard assessment procedure described by Form SA 1 of the

Meat and Livestock Commission (MLC). This included an assessment of overall subcutaneous fat cover measured on a seven point scale where 1 = extremely little fat and 7 = extremely fat. Overall conformation, defined as depth of fleshing (muscle and fat) relative to skeletal size, was also measured on a seven point scale where 1 = poor conformation and 7 = very good conformation. These carcasses were then cut in half through the centre of the vertebral column and the left side was double wrapped in stockinette, blast frozen, transported to the MLC Carcass Dissection Unit at Blisworth and stored until dissection.

The half carcass was subjected to a standard physical dissection procedure (R.J. Smith, 1970, unpublished mimeograph; see Appendix 1) in which the side was cut into eight standard joints using anatomical reference points, Figure 3.1. Each joint was separated by butchers knife into lean, subcutaneous fat, intermuscular fat, bone and waste. Two physical measurements made during dissection have been analysed in this work. These were (a) caliper subcutaneous fat depth measured on the cut surface at the 12th rib at a distance of 4 cm from the mid-line on the exposed posterior face of the best end neck, and (b) eye-muscle area: the area of the M. longissimus dorsi muscle taken from a photograph of the cut surface and measured using a d-mac pencil follower.

Before analysis, the data were examined and lambs with incomplete records or outlying measurements for some traits were removed. The data sets analysed were: (1) growth traits to 12 weeks for 2585 lambs, the progeny of 102 sires; (2) growth traits to slaughter for 1884 lambs, the progeny of 79 sires; and (3) half-carcass dissection traits for 956 lambs, the progeny of 65 sires.

Figure 3.1



STANDARDISED JOINTS USED IN M.L.C LAMB DISSECTION TECHNIQUE

3.2.2 Serial Slaughter Trial

In order to provide information about breed differences in carcass composition over a range of slaughter weights a serial slaughter trial was carried out in 1976 and 1977. Details of the flock management and dissection techniques given in Section 3.2.1 are also relevant to this trial.

Lambs were slaughtered according to a serial design based upon age. Eleven slaughter groups of 4 lambs/breed of sire were used. The first eight groups were slaughtered at four-weekly intervals between 13 weeks and 41 weeks of age. During this period all experimental animals were grazed on grass/clover pastures and forage crops. Three groups of lambs were overwintered. Two of these groups were stored and a third was fed to maintain growth and finish over winter. One store group and the 'fed' group were slaughtered at approximately 51 weeks of age. The final group was pasture fed until slaughter at approximately 65 weeks of age (1976 born lambs) or 58 weeks of age (1977 born lambs).

Variation in age of lambs at slaughter was reduced by selecting lambs born over a limited period of time, 11 days in 1976 and 15 days in 1977. Only lambs born and reared as singles or twins were used. Six breeds of sire were used in each year of the experiment. In 1976 the sire breeds used were Dorset Down, Ile de France, Oldenburg, Oxford, Suffolk and Texel. In 1977 the Ile de France and Oldenburg breeds were replaced by the Southdown and Cotswold. Each breed of sire was represented by 4 sires per year with different sires being used each year. Only 3 Texel sires produced progeny in 1976. The number of lambs per sire are given in Table 3.1. The

Table 3.1 Numbers of lambs (classified by year, breed and sire) in the serial slaughter trial which provide carcass dissection information

Year	1976				1977			
Sire code within breed	1	2	3	4	1	2	3	4
Breed of sire								
Cotswold	-	-	-	-	6	13	13	11
Dorset Down	13	12	12	7	8	10	9	17
Ile de France	10	10	14	9	-	-	-	-
Oldenburg	12	8	11	12	-	-	-	-
Oxford	14	8	11	10	8	12	11	11
Southdown	-	-	-	-	10	12	11	10
Suffolk	6	12	11	15	5	11	12	12
Texel	11	9	22	-	9	10	12	10

crossbred ewe types, the ages of the ewes and their contributions of lambs are given in Table 3.2. The majority of lambs were reared by 2 and 3 year old ewes. However, year, ewe age and crossbred ewe type were partially confounded.

In 1976 lambs were allocated to slaughter groups at random within breed of sire. In 1977 lambs were allocated to slaughter group at random within breed of sire, crossbred ewe type, ewe age, sex and rearing type sub-class to give a balanced design for these factors. In both years 4 lambs per sire breed were maintained as spares.

A number of lambs were lost during the course of the trial. In 1976 carcass dissection data was not available for one lamb for each of the Ile de France, Oldenburg and Oxford breeds in slaughter group 5 or for 2 Texel lambs (1 lamb in each of slaughter groups 3 and 6). In 1977 carcass dissection data were available for all lambs but data for 10 lambs in slaughter group 1 were not used in the analysis because weight losses between slaughter and the completion of dissection were greater than 10%, i.e.

$$100 - \frac{2 \times \Sigma \text{ kidney, KKCF and joint weights after dissection} \times 100}{\text{Cold dead weight}} > 10 .$$

The distribution of these lambs between breeds was as follows: Cotswold (1), Oxford (2), Texel (3) and Suffolk (4).

Table 3.2 Number of lambs by year, breed of dam and ewe age in the serial dissection trial

Breed of dam	1976		1977	
	Number of lambs	Age of ewe (years)	Number of lambs	Age of ewe (years)
(F ×(EF × DH))× BF	49	2, 3	23	3
(F ×((EF × BL)× DH))× BF	5	2, 3	11	3
(F ×(EF × BL))× BF	67	2, 3	33	3
(F ×(BL × DH))× BF	21	2, 3		
BL × BF	114	1*,2,3	88	2, 3
Texel × BF	3	1	41	2
Oldenburg × BF	-	-	29	2
BF	-	-	27	2

* 3 lambs

F = Finn,

EF = East Friesland,

DH = Dorset Horn,

BF = Blackface.

3.3 STATISTICAL METHODS

3.3.1 Introduction

Statistical analyses of both the Fixed Slaughterweight Trial and the Serial Slaughter Trial were carried out using the COMPREG least squares statistical package (Russell, 1973). A further analysis of the Fixed Slaughterweight Trial data was made using the Hierarchical Analysis of Variance programme package (Thompson, 1968) to estimate genetic parameters.

In the least squares analyses recorded information about each animal's pedigree (breed, sire, dam) was combined with information about environmental factors (e.g. year, age of dam, rearing type and sex) which affected performance in a mathematical model to explain variation in the dependent traits. In general, such models take the form:

$$Y_{ijk} = \mu + B_i + S_j + e_{ijk}$$

where, for example, Y_{ijk} is the observation of the dependent variable Y on the kth individual (k = 1, ..., n) of the ith breed (i = 1, ..., b) and the jth sex (j ; 1, ..., S), μ represents the overall mean and e_{ijk} is random error. In the method of least squares the values of μ, B_i and S_j are chosen which minimise the sums of squares of the errors. That is, the method minimises the term :

$$\Sigma(Y - \mu - B_i - S_j)^2 .$$

The method assumes that all factors are independent and that the errors are uncorrelated and normally distributed with zero mean and variance σ_e^2. The fitted values of each level of a factor are presented as deviations from the overall mean such that the sum of the fitted values is equal to zero.

In constructing the analysis of variance table and in forming the relevant tests of significance of effects, attention must be paid to the classification of the factors studied as either fixed or random effects. Factors are classified as random when specific differences between individuals are not of major interest but important inferences are to be made about the populations from which they were drawn. For the fixed effects information is required about the average differences between each level of a factor so classified. In this study sires and dams were considered to be random and all other factors were classified as fixed. It could be argued that years should be classified as random. However this was not done since the experiments were carried out in consecutive years and the effects of years may be considered to be correlated to one another. Furthermore the objective of including years in the model was to estimate correction factors for this source of variation, rather than to estimate the variance between years.

The implications of this classification of factors for the statistical tests of significance can be seen by considering the expectations of the mean squares for a model which includes a term for the mean (μ), breed of sire (B_i), sire within breed of sire (S_{ij}) and error (e_{ijk}).

$$Y_{ijk} = \mu + B_i + S_{ij} + e_{ijk} .$$

The expectations of the mean squares are shown in Table 3.3. If sires are considered to have fixed effects then the correct test of the significance of the effect breed of sire is against the error mean square. However, if sires are considered to have random effects then the correct test of breed of sire is against the

Table 3.3 Expectations of the mean squares for a model which includes breed of sire, sire/breed of sire and error

	Expectation of the mean square when sires have:	
	fixed effects	random effects
Breed of sire	$\sigma_e^2 + k_2\Delta_B^2$	$\sigma_e^2 + k_1\sigma_S^2 + k_2\Delta_B^2$
Sire/breed of sire	$\sigma^2 + k_1\Delta_S^2$	$\sigma_e^2 + k_1\sigma_S^2$
Error	σ_e^2	σ_e^2

between sires mean square. In practice the test of breed of sire against the residual error would overestimate the significance of this effect. Similarly, when models include effects for factors which may vary within sires, such as breed of dam, age of dam, rearing type and dams, then the correct tests of significance are against the between dams mean square. Consequently, in this study, the approach has been to construct a nested analysis of variance involving sires nested within breed of sire and year, dams nested within sire and individuals nested within dams. In both trials dams were assumed to be different in each year of the experiment.

In the following sections the statistical methods used in each trial are outlined in more detail. Examples of each analytical model are given in Appendices 2, 3 and 5.

3.3.2 Fixed Slaughterweight Trial

3.3.2.1 Estimation of fixed effects

The four basic models used to construct the analysis of variance are shown in Table 3.4. Model 1 included fixed effects only and these were fitted directly. In Models 2, 3 and 4 factors with large numbers of classes, for which fitted constants were not required, were fitted by absorption, that is by absorbing the least squares equations for these factors into the other equations. The information required to estimate the error mean squares (E.M.S.) for each test included the residual degrees of freedom (R.D.F.) and the residual sums of squares (R.S.S.) of each model. The M.S. for the breed of dam × sire interaction were estimated by (RSS(2) - RSS(3))/(RDF(2) - RDF(3)) and the E.M.S. for the test of significance was estimated by (RSS(3) - RSS(4))/(RDF(3) - RDF(4)). Where this

Table 3.4 The basic models used to construct the analysis of variance table (fixed slaughterweight data)

Factor	Model number			
	1	2	3	4
Breed of sire	F[#]	A[†]	A	A
Breed of dam	F	F	A	A
Year	F	A	A	A
Breed of sire × breed of dam	F	F	A	A
Breed of sire × year	F	A	A	A
Breed of dam × year	F	F	A	A
Sires/(breed of sire, year)	-	A	A	A
Breed of dam × sire/(breed of sire, year)	-	-	A	A
Dams/breed of dam/sires/(breed of sire, year)	-	-	-	A

[#]F = effect fitted directly

[†]A = effect fitted by absorption

interaction was not significant the values (RSS(2) - RSS(4))/(RDF(2) - RDF(4)) and (RSS(1) - RSS(2))/(RDF(1) - RDF(2)) were used as estimates of the M.S. between dams and between sires respectively. Finally the E.M.S. of model 4 was used as an estimate of the variation between litter mates.

Factors and their interactions which were included in the analysis were fitted in each model in which the variation had not been removed by the absorption process. Estimates of the overall least squares means were taken from model 1 and fitted values, sums of squares and mean squares for each factor were taken from the last model in which they appeared. Thus information for sire breed, year and sire breed × year was taken from model 1, information for dam breed, ewe age, birth-rearing type, dam breed × sire breed and dam breed × year was taken from model 2 and information for sex and slaughter group was taken from model 4.

Where a factor was found to have a significant effect ($P < 0.05$) upon a trait differences between levels of the factor were tested using Duncan's multiple range test as modified by Kramer (1957).

3.3.2.2 Estimation of genetic parameters

Genetic parameters were estimated from the Fixed Slaughter-weight Trial data. The nested analysis of variance between sires within breed of sire × year subclass, between dams within sire and within dams was reconstructed using a standard Hierarchical Analysis of Variance programme package (Thompson, 1968). This programme allows covariate adjustment of discrete classes (e.g. rearing type) by fitting 'dummy' variables (0 if class is absent,

1 if present) for each individual. Adjustment can also be made for continuous variates by regression. The programme estimates components of variance and covariance from the analysis of variance by equating the mean squares to their expectations under the assumption that all elements, except the mean, are random variables (Method 1 of Henderson, 1953).

Heritabilities were estimated by $4\hat{\sigma}^2_S/\hat{\sigma}^2_T$, where $\hat{\sigma}^2_T = \hat{\sigma}^2_S + \hat{\sigma}^2_D + \hat{\sigma}^2_R$ where the subscripts S, D and R refer to sire, dam and residual components respectively. A litter variance was estimated by $(\hat{\sigma}^2_D - \hat{\sigma}^2_S)/\hat{\sigma}^2_T$. Phenotypic correlations were estimated by $COV_T(X,Y)/\sqrt{(\hat{\sigma}^2_{TX} \cdot \hat{\sigma}^2_{TY}}$ and genetic correlations by $COV_S(X,Y)/\sqrt{(\hat{\sigma}^2_{SX} \cdot \hat{\sigma}^2_{SY}}$. The standard errors of the estimates were calculated using the general formulae of Becker (1975).

3.3.3 Serial Slaughter Trial

Separate analyses of the data were carried out to examine

1) Growth performance to 12 weeks
2) Liveweight and tissue growth relative to age
3) Carcass and tissue growth relative to liveweight
4) Tissue growth relative to side weight.
5) Fat deposition relative to lean weight
6) Lean growth relative to bone weight.

In each analysis the four basic models shown in Table 3.5 were used to construct nested analysis of variance tables. The sire × breed of dam interaction was not tested in these analyses. As all the sire breeds were not represented in both years of the experiment the effect of the breed of sire × year interaction could not be estimated directly. Therefore breed of sire and year were fitted in Model 1 of

Table 3.5 The basic models used to construct the analysis of variance table (serial slaughter data)

Factor	Model number			
	1	2	3	4
Breed of sire	F[#]	-	-	-
Year	F	-	-	-
Breed of sire - year (12 levels)	-	F	A[†]	A
Breed of dam/(breed of sire, year)	F	F	F	A
Sires/(breed of sire, year)			A	A
Dams/breed of dam/sires/(breed of sire, year)				A

[#]F = effect fitted directly

[†]A = effect fitted by absorption

the analysis and a factor which contained 12 subclasses of breed of sire by year (e.g. Dorset Down, Year 1; Dorset Down, Year 2; Ile de France, Year 1; Cotswold, Year 2; etc.) was fitted in Model 2. The difference between the residual sums of squares of Models 1 and 2 was used as an estimate of the sum of squares due to the breed of sire × year interaction.

In all analyses the following interactions were examined : sex × year, sex × sire breed, sex × dam breed, sex × ewe age, rearing type × year, rearing type × sire breed, rearing type × dam breed, rearing type × sex. In the analysis of liveweight and tissue weights against time the interactions of slaughter group with year, sire breed, dam breed and ewe age were examined. The 11 levels of the slaughter group factor were reduced to 4 by combining slaughter groups 1-3, 4-6 and 7-10 before interaction terms were fitted.

The examination of interaction terms was made by fitting interactions either singly or in different combinations with other interactions in an attempt to avoid correlations between interaction terms affecting the conclusions about the importance of each interaction.

In all analyses of carcass tissue weights the data were transformed to logarithms to base 10. The log-log regressions of tissue weights relative to liveweight and to each other were fitted within dams. Individual regressions were fitted for years, sire breeds, dam breeds, ewe age and sex. Differences between slopes were examined and when found to be non-significant ($P < 0.05$) the pooled within subclass regression slope was used. Curvilinearity in the pooled log-log regression was tested for by fitting a term

for $(\log_{10} X)^2$.

Least squares means and fitted values for the fixed effects were estimated after regression to the mean of $\log_{10} X$.

Where a factor was found to have a significant ($P < 0.05$) effect upon the trait, differences between levels of the factor were tested using Kramer's (1957) modification of Duncan's Multiple range test. The antilogs of each mean are presented in tables in Chapter 7. Since the antilogs of the standard errors would not be meaningful these have not been included.[1]

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[1] Tables of least squares means, fitted values and their standard errors in logarithmic form are available on request from the author.

CHAPTER 4

EFFECTS OF GENOTYPE AND ENVIRONMENTAL FACTORS UPON GROWTH AND CARCASS COMPOSITION AT FIXED SLAUGHTER WEIGHTS OF 35 kg AND 40 kg

4.1. INTRODUCTION

Unadjusted means and standard deviations for all traits are given in Table 4.1. For liveweights of standard ages the fixed effects explained approximately thirty percent of the total variation but the proportion of total variation explained in growth rates declined as the age of the lamb increased. In general the fixed effects did not explain as high a proportion of the total variation for carcass traits as they did for liveweight.

4.2 LIVEWEIGHT GROWTH

4.2.1 Interaction terms

The sire by breed of dam interaction, which had important consequences with respect to the validity of the statistical model, was not significant for any trait considered.

The breed of sire by year interaction was significant for a number of preweaning growth traits (Table 4.2), the interaction being largely due to the relatively high performances of the Texel and Ile de France breeds in 1974 and of the Oldenburg in 1976.

The breed of dam by year interaction was significant only for slaughter age (Table 4.3) and average daily gain from birth to slaughter. The differences between dam breeds were not large in 1972 and 1973 but the Greyface had a much higher level of performance than the ABRO Dam Line in 1974 and 1975.

The breed of sire by breed of dam interaction was significant only for slaughter age. The Oxford, Texel and Dorset Down were

Table 4.1 Means and standard deviations calculated from unadjusted data, and the pooled within breed residual standard deviations after correction for fixed effects

Trait	Mean	Standard deviation	Residual standard deviation
Birthweight (kg)	4.2	1.02	0.68
4 week weight "	12.8	2.99	1.91
8 week weight "	21.2	4.23	2.82
12 week weight "	28.6	5.12	3.58
Average daily gains (g/day)			
Birth-4 weeks	280	71	52
4 - 8 weeks	297	72	59
8-12 weeks	268	69	63
Birth-12 weeks	282	57	39
Birth-slaughter	241	68	48
Slaughter age (days)	155	55	41
Killing-out %	43.7	3.61	2.96
Carcass weight/day of age (g/day)	121	43	29
Side weight (kg)	8.24	1.15	0.83
Tissue in side %			
Lean	55.7	4.37	3.30
Bone	16.1	2.01	1.65
Fat (including KKCF)	26.7	5.65	4.33
Subcutaneous fat	12.4	3.30	2.53
Intermuscular fat	11.0	2.07	1.71
KKCF	3.3	1.10	0.90
Lean weight/day of age (g/day)	65.5	21.31	16.75
Lean:bone ratio	3.48	0.39	0.32
Lean:fat ratio	2.22	0.69	0.54
Subcutaneous:intermuscular fat ratio	1.13	0.23	0.21
Back fat depth (mm)	4.03	2.06	1.84
Eye muscle area (cm^2)	10.8	1.69	1.58

youngest at slaughter when crossed with the Greyface, the Oldenburg was older and Suffolk and Ile de France were not affected by breed of dam (Table 4.3).

Breed of sire by slaughter group interactions did not approach significance at the five percent level for either slaughter age or average daily gain from birth to slaughter.

4.2.2 Environmental Effects

Year effects were highly significant for all traits (Tables 4.2 and 4.3).

The offspring of ewe lambs were lighter at birth and subsequent ages than lambs born to two year old dams which, in turn, were lighter than lambs reared by three year old dams. This pattern was also true for growth rates and slaughter age. However, in the pre-weaning growth phase, there was a trend for the average daily gains of the progeny of two year olds to approach those of lambs reared by three year old ewes as lamb age increased. This trend was most marked for the eight to twelve week period where the difference was barely significant ($P < 0.05$).

Single born and reared lambs were heavier at all ages, had higher growth rates and were younger at slaughter than lambs born in larger litters. Twin lambs reared as singles were heavier, faster gaining and thus younger at slaughter than twin lambs reared as twins, and similar trends were discernable amongst lambs born as triplets.

Lambs born as twins and reared as singles approached, but did not exceed, the growth rates of single-single lambs as age increased. Triplet born lambs reared as singles showed a non-significant tendency for faster growth than twin-twin lambs.

Table 4.2 Least squares means and fitted values for growth traits to 12 weeks

	Number	Liveweight (kg) at:				Average daily gains (g/day)			
		Birth	Four weeks	Eight weeks	Twelve weeks	0-4 weeks	4-8 weeks	8-12 weeks	0-12 weeks
Mean	2585	3.46	11.26	19.49	26.97	252.03	293.65	266.95	270.27
Sire breed		NS [1]	* *	***	***	*	**	***	***
Dorset Down	423	-0.05±0.04	-0.12±0.10^{ab}	-0.06±0.15^{b}	-0.26±0.19^{a}	-1.89±2.77^{ab}	2.04±3.10^{bc}	-7.18±3.35^{a}	-2.39±2.04^{a}
Ile de France	443	-0.12±0.04	-0.34±0.10^{a}	-0.49±0.15^{b}	-0.56±0.19^{ab}	-6.83±2.78^{a}	-5.46±3.11^{ab}	-2.45±3.36^{ab}	-5.11±2.05^{a}
Oldenburg	403	0.05±0.04	-0.05±0.10^{ab}	-0.24±0.15^{b}	-0.12±0.19^{a}	-3.43±2.76^{ab}	-6.83±3.09^{ab}	4.55±3.33^{bc}	-1.99±2.03^{a}
Oxford	424	0.11±0.04	0.45±0.10^{c}	0.83±0.15^{a}	1.29±0.19^{c}	10.73±2.81^{c}	13.40±3.15^{d}	16.77±3.40^{d}	13.72±2.07^{b}
Suffolk	447	0.01±0.03	0.12±0.10^{b}	0.44±0.14^{a}	0.75±0.18^{c}	3.49±2.69^{bc}	11.47±3.01^{cd}	11.21±3.25^{cd}	8.55±1.98^{b}
Texel	445	0.00±0.03	-0.06±0.10^{ab}	-0.47±0.14^{b}	-1.11±0.18^{b}	-2.07±2.64^{ab}	-14.62±2.95^{a}	-22.90±3.19	-12.77±1.94^{c}
Dam breed		***	***	***	***	***	NS	NS	**
Dam Line	1292	-0.27±0.02	-0.42±0.05	-0.48±0.07	-0.50±0.09	-5.13±1.29	-1.86±1.44	-1.04±1.56	-2.75±0.94
Greyface	1293	0.27±0.02	0.42±0.05	0.48±0.07	0.50±0.09	5.13±1.29	1.86±1.44	1.04±1.56	2.75±0.94

[1] Effect approached significance at the 5% level.

Table 4.2 continued

	No.	Liveweight (kg) at:				Average daily gains (g/day)			
		Birth	Four weeks	Eight weeks	Twelve weeks	0-4 weeks	4-8 weeks	8-12 weeks	0-12 weeks
Year		***	***	***	***	***	***	***	***
1972	154	-0.17±0.06^{e}	0.30±0.16^{ef}	1.24±0.24^{e}	2.28±0.30^{e}	15.75±4.37^{e}	33.39±4.89^{e}	37.15±5.28^{e}	28.25±3.21^{e}
1973	381	-0.14±0.03^{e}	-0.67±0.09^{g}	-0.31±0.14^{f}	-0.29±0.18^{f}	-17.47±2.57^{g}	13.11±2.88^{f}	0.48±3.11^{f}	-1.79±1.89^{f}
1974	656	-0.01±0.03^{f}	0.44±0.08^{e}	0.86±0.12^{e}	0.27±0.15^{f}	14.77±2.15^{e}	15.10±2.40^{f}	-21.24±2.59^{g}	3.32±1.58^{f}
1975	707	0.24±0.03^{g}	-0.04±0.08^{f}	-1.23±0.11^{g}	-1.01±0.14^{g}	-8.71±2.07^{f}	-42.65±2.32^{h}	8.08±2.51^{f}	-14.26±1.53^{g}
1976	687	0.08±0.03^{f}	-0.04±0.08^{f}	-0.57±0.12^{f}	-1.25±0.15^{g}	-4.34±2.26^{f}	-18.95±2.53^{g}	-24.46±2.73^{g}	-15.52±1.66^{g}
Ewe age (years)		***	***	***	***	***	***	***	***
One	422	-0.99±0.04^{i}	-3.07±0.11^{i}	-4.14±0.16^{i}	-4.72±0.21^{i}	-68.17±3.04^{i}	-37.99±3.39^{i}	-20.92±3.68^{i}	-43.14±2.23^{i}
Two	1191	0.29±0.02^{j}	0.83±0.07^{j}	1.18±0.09^{j}	1.39±0.12^{j}	17.85±1.79^{j}	12.49±2.00^{j}	7.40±2.17^{j}	12.74±1.31^{j}
Three	972	0.69±0.03^{k}	2.24±0.08^{k}	2.95±0.12^{k}	3.33±0.15^{k}	50.32±2.16^{k}	25.50±2.41^{k}	13.53±2.62^{k}	30.40±1.59^{k}
Sex		***	***	***	***	***	***	***	***
Female	1319	-0.16±0.02	-0.36±0.05	-0.57±0.07	-0.81±0.09	-6.45±1.26	-7.68±1.45	-8.41±1.54	-7.52±0.95
Wether	1266	0.16±0.02	0.36±0.05	0.57±0.07	0.81±0.09	6.45±1.26	7.68±1.45	8.41±1.54	7.52±0.95

Table 4.2 continued

	No.	Liveweight (kg) at:				Average daily gains (g/day)			
		Birth	Four weeks	Eight weeks	Twelve weeks	0-4 weeks	4-8 weeks	8-12 weeks	0-12 weeks
Birth-rearing type		N.T.†	***	***	***	***	***	***	***
1-1	466	1.42±0.05	4.58±0.14^{l}	6.12±0.21^{l}	7.00±0.26^{l}	102.06±3.85^{l}	55.17±4.29^{l}	31.65±4.65^{l}	64.29±2.82^{l}
2-1	96	0.64±0.07	1.86±0.20^{m}	2.72±0.29^{m}	3.19±0.37^{m}	39.05±5.47^{m}	30.90±6.10^{m}	17.06±6.61^{lm}	29.42±4.01^{m}
2-2	1474	0.38±0.04	0.55±0.12^{n}	0.58±0.17^{n}	0.64±0.22^{n}	5.06±3.16^{n}	1.15±3.53^{n}	1.99±3.83^{m}	2.82±2.32^{n}
3-1	18	-0.54±0.14	-0.03±0.40^{n}	0.69±0.59^{n}	1.39±0.75^{mn}	16.92±11.02^{mn}	25.87±12.29^{mn}	24.55±13.33^{m}	22.14±8.08^{mn}
3-2	175	-0.38±0.06	-1.13±0.17^{p}	-1.62±0.25^{p}	-2.03±0.31^{p}	-24.33±4.60^{p}	-17.29±5.13^{p}	-14.97±5.57^{n}	-19.03±3.37^{p}
3-3	339	-0.59±0.05	-2.56±0.14^{q}	-4.13±0.21^{q}	-5.09±0.27^{q}	-63.47±3.94^{q}	-56.24±4.39^{q}	-34.41±4.76^{p}	-51.91±2.89^{q}
4+	17	-0.94±0.15	-3.26±0.43^{q}	-4.37±0.63^{q}	-5.09±0.80^{q}	-75.27±11.74^{q}	-39.57±13.10^{q}	-25.87±14.20^{np}	-47.73±8.61^{q}
Regressions on:		***	***	NS	***	**	***	***	***
Birth date	2585	0.009±0.003	0.03±0.01	-0.01±0.01	-0.04±0.01	0.64±0.18	-1.33±0.20	-1.21±0.22	-0.58±0.13
Age deviation	2585	---	*** 0.31±0.02	*** 0.24±0.03	*** 0.28±0.04	NS 0.86±0.53	*** -2.55±0.59	NS 1.25±0.64	NS -0.13±0.39

† Not tested

Table 4.2 continued Fitted values (± s.e.) for the breed of sire × year interactions

Four week weight	1972	1973	1974	1975	1976
Dorset Down	0.05±0.29	-0.16±0.20	-0.13±0.16	0.21±0.16	0.02±0.17
Ile de France	-0.08±0.30	0.09±0.19	0.46±0.17	-0.46±0.16	-0.02±0.16
Oldenburg	0.17±0.28	0.07±0.20	-0.31±0.17	-0.26±0.17	0.33±0.16
Oxford	0.25±0.30	-0.14±0.20	-0.17±0.17	0.28±0.16	-0.22±0.16
Suffolk	-0.11±0.28	0.28±0.20	0.14±0.16	-0.09±0.16	-0.22±0.16
Texel	-0.28±0.28	-0.14±0.19	0.00±0.16	0.31±0.16	0.10±0.16
Eight week weight					
Dorset Down	0.33±0.43	-0.52±0.29	-0.41±0.24	0.59±0.24	-0.00±0.25
Ile de France	-0.28±0.44	0.38±0.29	0.70±0.24	-0.53±0.23	-0.26±0.24
Oldenburg	-0.15±0.41	-0.05±0.30	-0.21±0.25	-0.41±0.25	0.82±0.24
Oxford	0.07±0.44	0.13±0.30	-0.24±0.25	0.34±0.24	-0.30±0.24
Suffolk	0.15±0.41	0.73±0.30	-0.07±0.24	-0.44±0.23	-0.38±0.23
Texel	-0.12±0.40	-0.67±0.27	0.23±0.23	0.44±0.23	0.12±0.24
Twelve week weight					
Dorset Down	0.34±0.55	-0.73±0.37	-0.51±0.31	0.73±0.30	0.18±0.31
Ile de France	-0.13±0.56	0.43±0.37	0.98±0.31	-0.80±0.30	-0.48±0.30
Oldenburg	-0.46±0.53	-0.23±0.38	-0.03±0.32	-0.36±0.31	1.09±0.30
Oxford	0.42±0.56	0.10±0.38	-0.29±0.32	0.15±0.30	-0.38±0.30
Suffolk	0.28±0.52	1.01±0.38	-0.29±0.30	-0.55±0.30	-0.45±0.30
Texel	-0.45±0.51	-0.58±0.35	0.14±0.29	0.84±0.30	0.05±0.31

Table 4.2 continued Fitted values (± s.e.) for breed of sire × year interactions

	1972	1973	1974	1975	1976
Average daily gain 0 - 12 weeks					
Dorset Down	3.45±5.90	-8.82±3.99	-5.67±3.29	8.74±3.26	2.30±3.36
Ile de France	-1.90±6.02	4.80±3.93	10.12±3.34	-8.07±3.18	-4.95±3.26
Oldenburg	-6.93±5.66	-1.90±4.13	0.18±3.42	-3.37±3.36	12.02±3.23
Oxford	5.96±6.01	0.79±4.12	-4.10±3.47	1.37±3.22	-4.01±3.23
Suffolk	5.17±5.57	10.85±4.09	-3.34±3.24	-7.33±3.18	-5.36±3.18
Texel	-5.75±5.49	-5.71±3.74	2.79±3.16	8.67±3.20	0.00±3.33
Average daily gain 4 - 8 weeks					
Dorset Down	9.97±8.98	-12.73±6.07	-9.89±5.01	13.69±4.96	-1.04±5.11
Ile de France	-7.11±9.16	10.14±5.98	8.42±5.09	-2.75±4.83	-8.70±4.97
Oldenburg	-11.37±8.61	-4.48±6.28	3.48±5.21	-5.26±5.12	17.63±4.92
Oxford	-6.45±9.15	9.84±6.27	-2.54±5.28	1.98±4.90	-2.82±4.91
Suffolk	9.38±8.47	16.17±6.23	-7.51±4.93	-12.30±4.83	-5.73±4.84
Texel	5.58±8.35	-18.93±5.69	8.04±4.81	4.64±4.87	0.66±5.07
Average daily gain 4 - 12 weeks					
Dorset Down	5.29±6.93	-10.26±4.69	-6.89±3.87	9.08±3.83	2.78±3.94
Ile de France	-1.08±7.08	6.10±4.62	9.21±3.93	-6.05±3.73	-8.19±3.84
Oldenburg	-11.19±6.65	-5.38±4.85	5.03±4.02	-1.97±3.95	13.51±3.80
Oxford	3.15±7.07	4.26±4.84	-2.19±4.07	-2.22±3.79	-3.00±3.79
Suffolk	6.89±6.54	13.11±4.81	-7.68±3.81	-8.24±3.73	-4.08±3.74
Texel	-3.07±6.45	-7.84±4.40	2.53±3.71	9.40±3.76	-1.03±3.92

Table 4.3 Least squares means and fitted values for slaughter traits

	Number	Slaughter age (days)	ADG birth-slaughter (g/day)	KO%	Carcass weight (kg)	Carcass weight/ day of age (g/day)
Mean	1884	167.74	225.86	43.28	16.61	110.13
Sire breed		* *	* *	***	* *	* *
Dorset Down	317	5.62±2.53	-8.36±3.00	0.71±0.19[a]	0.23±0.09 [a]	-2.95±1.82
Ile de France	323	7.54±2.56	-7.53±3.04	0.57±0.19[a]	0.17±0.09 [a]	-2.97±1.84
Oldenburg	280	5.77±2.56	-7.96±3.04	-1.79±0.19[c]	-0.66±0.09 [c]	-7.80±1.83
Oxford	299	-15.60±2.60[a]	21.80±3.08[a]	-0.10±0.19[b]	0.04±0.09 [b]	11.02±1.86[a]
Suffolk	322	-8.11±2.47[a]	11.94±2.93[a]	-0.14±0.18[b]	-0.05±0.09 [b]	5.69±1.77[a]
Texel	343	4.78±2.39	-9.88±2.84	0.75±0.18[a]	0.26±0.09 [a]	-2.98±1.72
Dam breed		* *	* *	NS	NS	* *
Dam Line	917	3.67±1.19	-4.62±1.40	0.15±0.09	0.06±0.04	-2.82±0.85
Greyface	967	-3.67±1.19	4.62±1.40	-0.15±0.09	-0.06±0.04	2.82±0.85

Table 4.3 continued

	Number	Slaughter age (days)	ADG birth-slaughter (g/day)	KO%	Carcass weight (kg)	Carcass weight/ day of age (g/day)
Year		***	***	***	***	***
1972	153	-9.65±3.22[d]	14.16±3.82[d]	1.39±0.24[d]	0.47±0.12[d]	9.96±2.31[d]
1973	378	16.75±2.04[e]	-26.69±2.42[e]	-1.61±0.15[e]	-0.72±0.07[e]	-18.26±1.46[e]
1974	649	-14.19±1.81[d]	18.87±2.14[d]	1.36±0.13[d]	0.39±0.07[d]	13.75±1.30[d]
1975	704	7.09±1.74[f]	-6.33±2.07[f]	-1.14±0.13[e]	-0.14±0.06[e]	-5.45±1.25[e]
Ewe age (years)		***	***	***	***	***
One	401	39.92±2.57[g]	-52.82±3.03[g]	-1.66±0.19[g]	-0.83±0.09[g]	-35.19±1.83[g]
Two	869	-12.17±1.59[h]	14.66±1.87[h]	0.36±0.12[h]	0.21±0.06[h]	9.70±1.13[h]
Three	614	-27.75±1.95[i]	38.16±2.30[i]	1.30±0.14[i]	0.62±0.07[i]	25.49±1.39[i]
Sex		***	***	NS	NS	***
Female	992	6.52±1.43	-10.34±1.47	0.11±0.09	0.04±0.05	-5.39±0.81
Wether	892	-6.52±1.43	10.34±1.47	-0.11±0.09	-0.04±0.05	5.39±0.81

Table 4.3 continued

	Number	Slaughter age (days)	ADG birth-slaughter (g/day)	KO%	Carcass weight (kg)	Carcass weight/ day of age (g/day)
Birth-rearing type		***	***	***	***	***
1-1	369	-55.00 ± 3.60^{j}	75.39 ± 4.24^{j}	3.02 ± 0.26^{j}	1.24 ± 0.13^{j}	52.94 ± 2.56^{j}
2-1	63	-20.73 ± 5.29^{k}	35.60 ± 6.24^{k}	1.91 ± 0.38^{k}	0.86 ± 0.19^{k}	25.10 ± 3.76^{k}
2-2	1091	$-4.36\pm3.03^{\ell}$	$1.24\pm3.57^{\ell}$	$0.12\pm0.22^{\ell}$	$-0.01\pm0.11^{\ell}$	$1.14\pm2.15^{\ell}$
3-1	11	$-12.18\pm10.91^{k\ell}$	$19.66\pm12.87^{k\ell}$	$0.40\pm0.79^{k\ell}$	$0.46\pm0.39^{k\ell}$	$9.68\pm7.76^{k\ell}$
3-2	99	19.62 ± 4.63^{m}	-27.99 ± 5.45^{m}	-0.99 ± 0.34^{m}	-0.41 ± 0.17^{m}	-19.89 ± 3.29^{m}
3-3	240	42.95 ± 3.72^{n}	-58.84 ± 4.38^{n}	-2.03 ± 0.27^{n}	-0.78 ± 0.13^{n}	-37.81 ± 2.64^{n}
4+	11	29.71 ± 11.31^{mn}	-45.05 ± 13.33^{mn}	-2.42 ± 0.82^{n}	-1.35 ± 0.41^{n}	-31.15 ± 8.04^{mn}
Slaughter group		***	***	*	***	***
One (35 kg)	885	-18.65 ± 1.43	8.79 ± 1.47	-0.08 ± 0.07	-1.30 ± 0.05	5.29 ± 0.81
Two (40 kg)	999	18.65 ± 1.43	-8.79 ± 1.47	0.08 ± 0.07	1.30 ± 0.05	-5.29 ± 0.81
Regression on:		***	***	***	**	***
Birth date	1884	0.77 ± 0.16	-1.31 ± 0.19	-0.04 ± 0.01	-0.02 ± 0.01	-0.74 ± 0.11

Table 4.3 continued Fitted values[#] for significant interaction terms

	Number	Slaughter age (days)	ADG birth-slaughter (g/day)
Breed of dam × year			
Dam Line × 1972	91	-4.76±2.66	3.54±3.13
Dam Line × 1973	193	-1.84±1.88	4.08±2.22
Dam Line × 1974	291	1.49±1.62	-2.49±1.91
Dam Line × 1975	342	5.12±2.66	-5.14±1.90
Breed of dam × breed of sire			
Dorset Down × Dam Line	158	2.77±2.12	
Ile de France × Dam Line	161	-3.86±2.09	
Oldenburg × Dam Line	144	-4.32±2.25	
Oxford × Dam Line	140	-1.19±2.18	
Suffolk × Dam Line	153	4.51±2.11	
Texel × Dam Line	161	2.08±2.05	

[#]fitted values for the Greyface are equal but opposite in sign to those of the Dam Line for each year or sire breed.

The sex effect was significant for all growth traits. Females were lighter at all ages, had lower growth rates and were thirteen days older at slaughter than wether lambs.

Mean liveweights at slaughter were 35.74 kg for the lighter group (group 1) and 41.62 kg for the heavier (group 2). Lambs in group 1 were 37 days younger at slaughter than those of group 2 and average daily gains from birth to slaughter were 17.6 g/day higher.

The linear regression on birthdate was highly significant for all traits except eight week weight. Later born lambs were heavier at birth and four weeks but lighter at twelve weeks, their average daily gains from birth to four weeks were high whilst other growth rates were low with a consequent increase in slaughter age.

4.2.3 Breed of Sire

The breed of sire effect was significant for all growth traits except birthweight which, however, approached significance at the 5% level. The Oxford Down cross tended to have above average birthweights with a low value being found for the Ile de France cross. By twelve weeks of age the Oxford and Suffolk cross lambs were heavier, and Texel crosses were lighter than lambs of the other three breed crosses. This ranking of the breeds was also relevant for average daily gain from birth to weaning but consideration of pre-weaning daily gains in three 4-week periods showed consistently high rates of gain for the Oxford cross, whilst the differences between the Suffolk and Texel crosses and the other breeds were not well established until the four to eight week period. The growth rate of the Texel cross was particularly low between 8 and 12 weeks.

The Oxford and Suffolk crosses maintained their growth advantage in the post-weaning period being youngest at slaughter and having the highest average daily gains from birth to slaughter. However, the Texel cross appears to have had a high post-weaning growth rate and did not differ significantly from the Dorset Down, Ile de France and Oldenburg crosses for these traits.

4.2.4 Breed of Dam

Crossbred lambs of ABRO Dam Line breeding were lighter at all ages from birth to weaning and 7 days older at slaughter than the Greyface cross lambs. Average daily gains from birth to four weeks, birth to weaning and from birth to slaughter were lowest for the ABRO Dam Line cross lamb but did not differ significantly from the Greyface cross between four and twelve weeks of age.

4.3 CARCASS COMPOSITION

4.3.1 Interaction terms

Sire by breed of dam, breed of sire by year, slaughter group and breed of dam, and sex by slaughter group interactions were not significant for any trait. The breed of dam by year interaction was significant ($P < 0.05$) for lean weight/day of age, percentage intermuscular fat, subcutaneous fat : intermuscular fat ratio and eye-muscle area. The interaction for lean weight/day of age was due to the poor performance of the Greyface in 1973 relative to 1974 (Table 4.4). The remaining interactions were due to changes in rank. The Greyface had the lowest eye-muscle area in 1973 and the highest in other years, the highest subcutaneous fat : intermuscular fat ratio in 1974 when the mean was highest but the lowest for other years, the reverse being true for percentage intermuscular fat.

4.3.2 Environmental effects

Side weight, lean weight/day of age and eye-muscle area increased with age of ewe. The offspring of three year old ewes yielded carcasses with a higher proportion of total fat and lower lean : fat ratios than those of the offspring of one and two year old ewes. The offspring of ewe lambs had the highest lean : bone ratios.

The rearing type effect was significant for all traits except percent bone and lean : bone ratio. Increasing litter size resulted in reduced side weights and lean tissue growth rates. Trends in carcass composition relative to rearing type were not clear. However, single lambs tended to yield the fattest carcass and twins the leanest with intermediate values for triplets.

The sex effect was significant for all traits except side weight, eye-muscle area and caliper subcutaneous fat depth. Females were fatter, had marginally higher lean : bone ratio and lower weight of lean/day of age than wethers.

The regression on date of birth was not significant for any trait other than lean tissue growth rate, the earliest born lambs having the highest deposition of lean tissue per day of age.

Lambs slaughtered at 35 kg had lower side weights, higher proportions of lean and bone, lower lean : bone ratio and eye-muscle area and higher lean : fat ratio and lean tissue growth rate than lambs slaughtered at 40 kg.

4.3.3 Breed of Sire

The breed of sire effect explained a significant proportion ($P < 0.05$) of the variation in all carcass traits except side weight; however, the Oldenburg cross tended to give a lower side weight and

this is in keeping with the results for killing-out percent derived from the larger sample, Table 4.3.

The Oldenburg, Oxford and Suffolk cross lambs did not differ significantly in the proportion of dissectible lean and bone in the carcass, lean : bone and lean : fat ratios, caliper subcutaneous fat depth or eye-muscle area. The Suffolk had 1.7% more fat in the carcass than the Oldenburg, but neither differed significantly from the Oxford cross. Dorset Down cross lambs yielded a carcass containing a higher proportion of fat, higher lean : bone ratio but lower lean : fat ratio than the three breeds described above. The carcass of the Ile de France cross lamb was intermediate between the Dorset Down and Suffolk for percentage lean and fat but did not differ significantly from the Dorset Down cross for lean : bone ratio. The proportion of lean in the carcass of the Texel cross lamb was high (3.7percentage points above the least squares mean for all breeds). This was associated with a low level of fat, a moderately low proportion of bone and thus high lean : bone and lean : fat ratios.

Lean tissue growth rate, as estimated by weight of lean per day of age, was highest in the Oxford and Suffolk crosses with the Oxford cross tending to have a higher value. The high lean content of the Texel cross carcass resulted in a lean tissue growth rate which did not differ significantly from that of the Suffolk cross lamb, despite a high slaughter age. The other breeds did not differ from one another for this trait. Eye-muscle area was highest in the Texel cross and lowest in the Oldenburg, the average difference between them being 1.1 cm^2.

Table 4.4 Least squares means and fitted constants for carcass composition at constant liveweight

	Number	Side weight (kg)	% Lean	% Bone	% Fat	Lean: bone ratio	Lean: fat ratio
Mean	956	8.32	55.31	15.89	27.30	3.52	2.15
Sire breed		*	***	***	***	***	***
Dorset Down	154	0.08±0.06	-2.15±0.25^{a}	-0.93±0.12^{a}	3.13±0.33^{a}	0.06±0.02^{a}	-0.34±0.04^{a}
Ile de France	163	0.06±0.06	-1.06±0.25^{ab}	-0.47±0.12^{ab}	1.56±0.32^{b}	0.03±0.02^{a}	-0.19±0.04^{ab}
Oldenburg	138	-0.29±0.06^{a}	0.64±0.26^{c}	0.77±0.13^{c}	-1.52±0.34^{e}	-0.12±0.03^{b}	0.13±0.04^{c}
Oxford	156	0.03±0.06	-0.56±0.25^{bc}	0.65±0.12^{c}	-0.11±0.32^{ce}	-0.17±0.02^{b}	-0.04±0.04^{bc}
Suffolk	158	0.01±0.06	-0.55±0.24^{bc}	0.34±0.12^{c}	0.20±0.32^{b}	-0.11±0.02^{b}	-0.04±0.04^{bc}
Texel	187	0.10±0.06	3.68±0.23^{d}	-0.35±0.11^{b}	-3.26±0.30^{d}	0.31±0.02^{c}	0.48±0.04^{d}
Dam breed		NS	NS	***	NS	***	NS
Dam Line	442	0.01±0.03	0.14±0.11	-0.39±0.06	0.26±0.15	0.09±0.01	-0.03±0.02
Greyface	514	-0.01±0.03	-0.14±0.11	0.39±0.06	-0.26±0.15	-0.09±0.01	0.03±0.02

Table 4.4 continued Comparison at constant liveweight

	% Subcutaneous fat	% Intermuscular fat	% KKCF	Subcutaneous: intermuscular fat	Subcutaneous fat depth (mm)	Eye-muscle area (cm^2)	Lean weight/ day of age (g/day)
Mean	12.64	11.12	3.55	1.14	4.32	10.69	64.62
Sire breed	***	***	**	*	**	**	**
Dorset Down	1.74 ± 0.19^{a}	1.01 ± 0.13^{a}	0.38 ± 0.07^{a}	0.05 ± 0.02^{a}	0.67 ± 0.15^{a}	0.15 ± 0.13^{ab}	-4.50 ± 1.26^{a}
Ile de France	0.74 ± 0.19^{b}	0.70 ± 0.13^{ab}	0.12 ± 0.07^{ab}	-0.00 ± 0.02^{abc}	0.42 ± 0.15^{ab}	0.23 ± 0.13^{ab}	-2.06 ± 1.25^{a}
Oldenburg	-0.76 ± 0.20^{c}	-0.54 ± 0.13^{d}	-0.21 ± 0.07^{b}	-0.01 ± 0.02^{bc}	-0.41 ± 0.15^{cd}	-0.55 ± 0.13^{c}	-3.83 ± 1.30^{a}
Oxford	0.07 ± 0.19^{bc}	-0.07 ± 0.13^{cd}	-0.11 ± 0.07^{b}	0.02 ± 0.02^{ab}	0.19 ± 0.15^{abc}	-0.24 ± 0.12^{bc}	5.63 ± 1.25^{b}
Suffolk	-0.12 ± 0.19^{bc}	0.36 ± 0.13^{bc}	-0.04 ± 0.07^{b}	-0.05 ± 0.02^{c}	-0.14 ± 0.15^{bcd}	-0.14 ± 0.13^{bc}	2.82 ± 1.23^{bc}
Texel	-1.67 ± 0.18^{d}	-1.46 ± 0.12^{e}	-0.14 ± 0.06^{b}	-0.00 ± 0.01^{abc}	-0.73 ± 0.14^{d}	0.56 ± 0.12^{a}	1.94 ± 1.16^{c}
Dam breed	NS	NS	***	*	NS	NS	***
Dam Line	0.08 ± 0.09	0.05 ± 0.06	0.22 ± 0.03	0.02 ± 0.01	0.09 ± 0.07	-0.05 ± 0.06	-3.36 ± 0.57
Greyface	-0.08 ± 0.09	-0.05 ± 0.06	-0.22 ± 0.03	-0.02 ± 0.01	-0.09 ± 0.07	0.05 ± 0.06	3.36 ± 0.57

Table 4.4 continued Comparison at constant liveweight

	Number	Side weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio	Lean:fat ratio
Year		***	***	***	***	**	***
1973	273	-0.48±0.04^{f}	1.56±0.18^{f}	0.11±0.09^{f}	-1.54±0.23^{f}	0.08±0.02^{f}	0.18±0.03^{f}
1974	325	0.42±0.04^{g}	-1.71±0.18^{g}	-0.52±0.09^{g}	2.18±0.24^{g}	-0.00±0.02^{g}	-0.27±0.03^{g}
1975	358	0.06±0.05^{h}	0.15±0.19^{h}	0.41±0.10	-0.64±0.25^{f}	-0.08±0.02^{h}	0.09±0.03^{f}
Ewe age (years)		***	*	*	*	*	*
One	88	-0.38±0.09^{i}	0.65±0.35^{i}	-0.10±0.18^{i}	-0.58±0.46^{i}	0.08±0.04^{i}	0.05±0.06^{i}
Two	710	-0.02±0.05^{j}	0.19±0.20^{i}	0.27±0.10^{ij}	-0.42±0.27^{i}	-0.05±0.02^{j}	0.05±0.03^{i}
Three	158	0.40±0.07^{k}	-0.84±0.29^{j}	-0.17±0.15^{i}	1.01±0.38^{j}	-0.02±0.03^{j}	-0.10±0.05^{j}
Sex		NS	***	***	***	**	***
Female	502	-0.01±0.04	-0.65±0.16	-0.45±0.08	1.16±0.21	0.06±0.02	-0.12±0.03
Wether	454	0.01±0.04	0.65±0.16	0.45±0.08	-1.16±0.21	-0.06±0.02	0.12±0.03

Table 4.4 continued Comparison at constant liveweight

	% Subcutaneous fat	% Intermuscular fat	% KKCF	Subcutaneous: intermuscular fat	Subcutaneous fat depth (mm)	Eye-muscle area (cm^2)	Lean weight/ day of age (g/day)
Year	***	**	***	***	NS	*	***
1973	-1.23±0.14[f]	-0.44±0.09[f]	0.13±0.05[f]	-0.07±0.01[f]	-0.10±0.10	-0.15±0.09[f]	-4.89±0.90[f]
1974	1.63±0.14[g]	0.36±0.09[g]	0.19±0.05[f]	0.12±0.01[g]	0.30±0.11	0.32±0.09[g]	8.64±0.91[g]
1975	-0.39±0.15[h]	0.08±0.10[g]	-0.32±0.05[g]	-0.05±0.01[f]	-0.20±0.12	-0.17±0.10[f]	-3.75±0.97[f]
Ewe age (years)	*	*	NS	NS	NS	***	***
One	-0.47±0.27[i]	-0.16±0.18[i]	0.05±0.10	-0.03±0.02	-0.28±0.21	-0.62±0.18[i]	-16.85±1.80[i]
Two	-0.13±0.16[i]	-0.19±0.18[i]	-0.10±0.06	0.01±0.01	-0.08±0.12	-0.04±0.11[j]	1.80±1.04[j]
Three	0.59±0.22[j]	0.36±0.15[j]	0.05±0.08	0.02±0.02	0.36±0.18	0.66±0.16[k]	12.57±1.48[k]
Sex	***	*	***	**	NS	NS	***
Female	0.65±0.12	0.22±0.09	0.29±0.04	0.04±0.01	0.20±0.10	-0.14±0.09	-3.71±0.71
Wether	-0.65±0.12	-0.22±0.09	-0.29±0.04	-0.04±0.01	-0.20±0.10	0.14±0.09	3.71±0.71

Table 4.4 continued Comparison at constant liveweight

	Number	Side weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio	Lean:fat ratio
Rearing type		***	***	NS	***	NS	**
Single	181	$0.37\pm0.06^{\ell}$	$-0.81\pm0.25^{\ell}$	-0.13 ± 0.13	$0.94\pm0.32^{\ell}$	-0.03 ± 0.02	$-0.09\pm0.04^{\ell}$
Twin	718	-0.30 ± 0.05^{m}	0.69 ± 0.20^{m}	0.22 ± 0.10	-0.97 ± 0.27^{m}	-0.00 ± 0.02	0.09 ± 0.03^{m}
Triplet	57	-0.07 ± 0.08^{n}	0.13 ± 0.32^{m}	-0.09 ± 0.17	$0.03\pm0.43^{\ell m}$	0.03 ± 0.03	$-0.00\pm0.05^{\ell m}$
Slaughter group		***	***	***	***	***	***
One (35 kg)	451	-0.66 ± 0.04	1.01 ± 0.16	0.60 ± 0.08	-1.67 ± 0.20	-0.07 ± 0.02	0.19 ± 0.02
Two (40 kg)	505	0.66 ± 0.04	-1.01 ± 0.16	-0.60 ± 0.08	1.67 ± 0.20	0.07 ± 0.02	-0.19 ± 0.02
Regression on:		**	NS	NS	NS	NS	NS
Birth date	956	-0.01 ± 0.005	-0.00 ± 0.02	0.01 ± 0.01	-0.01 ± 0.02	-0.00 ± 0.00	0.00 ± 0.00

Table 4.4 continued Comparison at constant liveweight

	% Subcutaneous fat	% Intermuscular fat	% KKCF	Subcutaneous: Intermuscular fat	Subcutaneous fat depth (mm)	Eye-muscle area (cm^2)	Lean weight/ day of age (g/day)
Rearing type	***	**	***	*	***	***	***
Single	$0.62\pm0.19^{\ell}$	$0.44\pm0.13^{\ell}$	$-0.13\pm0.07^{\ell}$	$0.01\pm0.02^{\ell}$	$0.12\pm0.15^{\ell}$	$0.69\pm0.13^{\ell}$	$16.78\pm1.27^{\ell}$
Twin	-0.55 ± 0.16^{m}	-0.17 ± 0.11^{m}	-0.24 ± 0.06^{m}	-0.03 ± 0.01^{m}	-0.52 ± 0.12^{m}	-0.09 ± 0.11^{m}	-1.28 ± 1.05^{m}
Triplet	-0.06 ± 0.25^{m}	-0.27 ± 0.17^{m}	0.37 ± 0.09^{n}	$0.03\pm0.02^{\ell}$	$0.41\pm0.20^{\ell}$	-0.60 ± 0.17^{n}	-15.51 ± 1.67^{n}
Slaughter group	***	***	***	***	***	*	***
One (35 kg)	-0.95±0.12	-0.41±0.09	-0.31±0.04	-0.05±0.01	-0.56±0.09	-0.17±0.08	4.53±0.67
Two (40 kg)	0.95±0.12	0.41±0.09	0.31±0.04	0.05±0.01	0.56±0.09	0.17±0.08	-4.53±0.67
Regression on:	NS	NS	NS	NS	NS	NS	***
Birth date	-0.02±0.01	-0.01±0.01	0.01±0.00	-0.00±0.00	0.00±0.01	-0.16±0.09	-0.30±0.09

Table 4.4 continued Comparison at constant liveweight

Fitted values# for significant interaction terms

	Number	% Subcutaneous fat	% Intermuscular fat	Subcutaneous : Intermuscular fat	Eye-muscle area (cm^2)	Lean weight/ day of age (g/day)
Breed of dam × year						
Dam Line × 1973	135	0.13±0.12	-0.12±0.08	0.26±0.10	0.23±0.08	2.12±0.80
Dam Line × 1974	148	0.07±0.12	0.21±0.08	-0.13±0.10	-0.09±0.08	-2.00±0.80
Dam Line × 1975	159	-0.20±0.12	-0.09±0.08	-0.13±0.10	-0.14±0.08	-0.10±0.76

fitted values for the Greyface are equal but opposite in sign to those of the Dam Line for each year.

4.3.4 Breed of Dam

The breed of dam effect was not significant for side weight but the carcass of the Greyface cross lamb contained a significantly higher ($P < 0.001$) percentage of bone and lower percentage KKCF, lean : bone ratio and subcutaneous fat : intermuscular fat ratios than the Dam Line cross. Lean tissue growth rate was highest for the Greyface cross lamb by 0.56 g/day of age.

4.3.5 Adjustment for side weight

Differences in measures of fatness due to year, rearing type and ewe age were largely removed by the inclusion in the model of a linear regression on side weight (Table 4.5). Year effects on percent total fat in the side were reduced and those for percent subcutaneous fat, percent intermuscular fat and eye-muscle area became non-significant. Rearing type and ewe age effects for percent lean, percent total fat, percent subcutaneous fat, percent intermuscular fat and lean : fat ratio also became non-significant. Ewe age effects for eye-muscle area and the effect of rearing type on subcutaneous fat : intermuscular fat ratio were similarly reduced. At constant side weight the progeny of ewe lambs had high lean : bone ratio whilst single lambs had lower values than twins and triplets for this trait.

The adjustment brought about small changes in ranking of sire breeds for caliper subcutaneous fat depth and eye-muscle area. The differences between the Oldenburg and Ile de France crosses for percent lean and between Oldenburg and Suffolk crosses for percent total fat became non-significant. Breed differences in the ratio of subcutaneous fat : intermuscular fat were reduced although the Suffolk cross had a low value for this trait.

Table 4.5 Least squares means and fitted constants for carcass composition at constant side weight

	Slaughter age (days)	Slaughter weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio	Lean:fat ratio
Mean	171.99	38.94	55.42	15.97	27.10	3.51	2.18
Sire breed	**	***	***	***	***	***	***
Dorset Down	2.23±3.09^{ab}	-0.30±0.17^{ab}	-2.01±0.23^{a}	-0.84±0.11^{a}	2.89±0.28^{a}	0.05±0.02^{a}	-0.31±0.04^{a}
Ile de France	3.89±3.06^{ab}	-0.48±0.17^{a}	-0.96±0.23^{ab}	-0.41±0.10^{ab}	1.39±0.28^{b}	0.02±0.02^{a}	-0.18±0.04^{ab}
Oldenburg	12.10±3.21^{a}	1.03±0.17^{d}	0.19±0.24^{b}	0.47±0.11^{c}	-0.75±0.29^{c}	-0.09±0.02^{b}	0.05±0.04^{c}
Oxford	-14.27±3.07^{c}	0.08±0.17^{bc}	-0.51±0.23^{b}	0.67±0.10^{c}	-0.18±0.28^{c}	-0.17±0.02^{b}	-0.03±0.04^{bc}
Suffolk	-6.82±3.02^{bc}	0.11±0.16^{bc}	-0.55±0.22^{b}	0.35±0.10^{c}	0.19±0.27^{bc}	-0.11±0.02^{b}	-0.04±0.04^{bc}
Texel	2.87±2.84^{ab}	-0.44±0.16^{a}	3.84±0.21^{c}	-0.25±0.10^{b}	-3.54±0.26^{d}	0.30±0.02^{c}	0.51±0.03^{d}
Dam breed	***	NS	***	NS	NS	***	NS
Dam Line	7.22±1.41	-0.11±0.08	0.16±0.10	-0.38±0.05	0.23±0.13	0.09±0.01	-0.02±0.02
Greyface	-7.22±1.41	0.11±0.08	-0.16±0.10	0.38±0.05	-0.23±0.13	-0.09±0.01	0.02±0.02

Table 4.5 continued Comparison at constant side weight

	% Subcutaneous fat	% Intermuscular fat	% KKCF	Subcutaneous: Intermuscular fat	Subcutaneous fat depth (mm)	Eye-muscle area (cm^2)	Lean weight/ day of age (g/day)
Mean	12.52	11.07	3.51	1.14	4.24	10.61	59.70
Sire breed	***	***	**	*	***	**	**
Dorset Down	1.60 ± 0.17^{a}	0.94 ± 0.12^{a}	0.35 ± 0.06^{a}	0.04 ± 0.02	0.54 ± 0.13^{a}	0.06 ± 0.11^{abc}	-4.40 ± 1.31^{a}
Ile de France	0.65 ± 0.16^{b}	0.66 ± 0.12^{a}	0.09 ± 0.06^{ab}	-0.01 ± 0.02	0.41 ± 0.13^{ab}	0.23 ± 0.11^{ab}	-1.58 ± 1.29^{a}
Oldenburg	-0.34 ± 0.17^{c}	-0.34 ± 0.13^{c}	-0.08 ± 0.06^{bc}	0.01 ± 0.02	-0.09 ± 0.14^{bc}	-0.35 ± 0.12^{c}	-4.00 ± 1.36^{a}
Oxford	0.04 ± 0.16^{bc}	-0.10 ± 0.12^{bc}	-0.12 ± 0.06^{bc}	0.02 ± 0.01	0.16 ± 0.13^{abc}	-0.26 ± 0.11^{c}	5.51 ± 1.30^{b}
Suffolk	-0.13 ± 0.16^{c}	0.37 ± 0.12^{ab}	-0.05 ± 0.06^{b}	-0.05 ± 0.01^{a}	-0.16 ± 0.13^{c}	-0.17 ± 0.11^{bc}	2.57 ± 1.28^{bc}
Texel	-1.83 ± 0.15^{d}	-1.53 ± 0.11^{d}	-0.18 ± 0.06^{c}	-0.01 ± 0.01	-0.85 ± 0.12^{d}	0.48 ± 0.11^{a}	1.90 ± 1.20^{c}
Dam breed	NS	NS	***	*	NS	NS	***
Dam Line	0.07 ± 0.07	-0.06 ± 0.05	0.21 ± 0.03	0.01 ± 0.01	0.09 ± 0.06	-0.03 ± 0.05	-3.00 ± 0.60
Greyface	-0.07 ± 0.07	0.06 ± 0.05	-0.21 ± 0.03	-0.01 ± 0.01	-0.09 ± 0.06	0.03 ± 0.05	3.00 ± 0.60

Table 4.5 continued Comparison at constant side weight

	Slaughter age (days)	Slaughter weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio	Lean:fat ratio
Year	***	***	***	***	**	***	**
1973	10.28±2.32[a]	0.59±0.13	0.82±0.17[a]	-0.39±0.08[a]	-0.25±0.21[a]	0.14±0.02[a]	0.04±0.03[a]
1974	-25.05±2.29[b]	-1.79±0.13	-1.05±0.17[b]	-0.09±0.08[a]	1.05±0.21[b]	-0.05±0.02[b]	-0.14±0.03[b]
1975	14.77±2.37[a]	1.20±0.13	0.23±0.18[a]	0.48±0.08[b]	-0.80±0.21[a]	-0.09±0.02[b]	0.11±0.03[a]
Ewe age (years)	***	*	NS	**	NS	**	NS
One	42.38±4.46[a]	0.57±0.25	0.10±0.32	-0.50±0.15[a]	0.40±0.40	0.13±0.03[a]	-0.05±0.05
Two	-10.21±2.57[b]	0.08±0.14	0.16±0.19	0.27±0.09[b]	-0.38±0.23	-0.06±0.02[b]	0.05±0.03
Three	-32.17±3.69[c]	-0.64±0.20	-0.26±0.27	0.23±0.13[b]	-0.02±0.33	-0.07±0.03[b]	0.01±0.04
Sex	**	NS	***	***	***	***	***
Female	5.63±1.73	-0.08±1.09	-0.67±0.15	-0.47±0.07	1.20±0.18	0.06±0.02	-0.13±0.02
Wether	-5.63±1.73	0.08±1.09	0.67±0.15	0.47±0.07	-1.20±0.18	-0.06±0.02	0.13±0.02

Table 4.5 continued Comparison at constant side weight

	% Subcutaneous fat	% Intermuscular fat	% KKCF	Subcutaneous: intermuscular fat	Subcutaneous fat depth (mm)	Eye-muscle area (cm^2)	Lean weight/ day of age (g/day)
Year	***	NS	***	***	*	NS	***
1973	-0.51±0.12[a]	-0.10±0.09	0.35±0.05[a]	-0.04±0.01[a]	0.39±0.10[a]	0.20±0.09	-4.49±0.98[a]
1974	0.99±0.12[b]	0.06±0.09	-0.01±0.05[b]	0.09±0.01[b]	-0.16±0.10[b]	0.02±0.09	9.13±0.97[b]
1975	-0.49±0.13[a]	0.04±0.09	-0.35±0.05[c]	-0.05±0.01[a]	-0.23±0.10[b]	-0.22±0.09	-4.64±1.00[a]
Ewe age (years)	NS	NS	*	NS	NS	NS	***
One	0.08±0.24	0.09±0.17	0.24±0.09[a]	-0.00±0.02	0.18±0.19	-0.31±0.17	-17.22±1.88
Two	-0.10±0.14	-0.18±0.10	-0.10±0.05[b]	0.01±0.01	-0.08±0.11	-0.04±0.10	4.49±1.08
Three	0.02±0.19	0.10±0.14	-0.14±0.07[b]	-0.01±0.02	-0.09±0.16	0.35±0.15	12.73±1.55
Sex	***	**	***	***	**	NS	***
Female	0.68±0.10	0.23±0.09	0.30±0.04	0.04±0.01	0.25±0.09	-0.10±0.08	-3.73±0.71
Wether	-0.68±0.10	-0.23±0.09	-0.30±0.04	-0.04±0.01	-0.25±0.09	0.10±0.08	3.73±0.71

Table 4.5 continued Comparison at constant sideweight

	Slaughter age (days)	Slaughter weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio	Lean:fat ratio
Rearing type	***	***	NS	NS	NS	**	NS
Single	-41.50±3.19[a]	-0.99±0.18[a]	-0.26±0.23	0.24±0.11	-0.02±0.28	-0.07±0.02[a]	0.02±0.04
Twin	-5.42±2.63[b]	-0.21±0.15[b]	0.27±0.19	-0.10±0.09	-0.20±0.23	0.04±0.02[b]	0.01±0.03
Triplet	46.92±4.13[c]	1.20±0.23[c]	-0.01±0.30	-0.14±0.14	0.22±0.37	0.03±0.03[b]	-0.02±0.05
Regression on:							
Birth date	*	NS	NS	NS	NS	NS	NS
	0.61±0.22	0.01±0.01	-0.02±0.02	-0.00±0.01	0.02±0.02	-0.00±0.002	-0.00±0.003
Side weight	***	***	***	***	***	***	***
	0.28±0.02	0.34±0.01	-0.02±0.001	-0.01±0.001	0.03±0.002	0.11±0.02†	-0.28±0.02†

† coefficient multiplied by 100

Table 4.5 continued Comparison at constant side weight

	% Subcutaneous fat	% Intermuscular fat	% KKCF	Subcutaneous: intermuscular fat	Subcutaneous fat depth (mm)	Eye-muscle area (cm^2)	Lean weight/ day of age (g/day)
Rearing type	NS	NS	***	NS	*	**	***
Single	0.08±0.17	0.19±0.12	-0.29±0.06[a]	-0.02±0.02	-0.29±0.14[a]	0.40±0.12[a]	16.68±1.34[a]
Twin	-0.12±0.14	0.03±0.10	-0.11±0.05[b]	-0.02±0.01	-0.20±0.11[a]	0.15±0.10[a]	-0.59±1.11[b]
Triplet	0.04±0.22	-0.22±0.16	0.41±0.08[c]	0.03±0.02	0.49±0.18[b]	-0.55±0.16[b]	-16.09±1.74[c]
Regression on:							
Birth date	NS	NS	***	NS	NS	NS	*
	0.00±0.01	0.00±0.01	0.01±0.004	0.00±0.01	0.01±0.01	-0.01±0.01	-0.24±0.09
Side weight	***	***	***	***	***	***	***
	0.02±0.001	0.01±0.001	0.47±0.04†	0.07±0.01†	0.01±0.001	0.01±0.001	-0.04±0.01

† coefficient multiplied by 100

4.3.6 Adjustment for percent subcutaneous fat

After adjustment to a constant level of subcutaneous fat (11.3%) in the side, the slaughter ages of the Texel and Oldenburg crosses were increased and those of the Dorset Down and Ile de France decreased relative to the mean slaughter age, in comparison to slaughter ages at constant liveweight (Table 4.6). Variation between breeds in percentage carcass composition was greatly reduced although the Texel maintained an advantage for % lean, lean : bone ratio and lean : fat ratio.

The difference in slaughter age due to dam breed in this comparison was twice the difference found when slaughter was at a constant weight and the Dam Line produced 0.46% more lean than the Greyface.

4.4 DISCUSSION

4.4.1 Introduction

Although the data for this analysis was collected from experimental lambs slaughtered at fixed liveweights, the means and standard deviations for carcass traits (Table 4.1) are close to those reported by Kempster and Cuthbertson (1977) for a sample of lambs drawn from commercial sources.

As the sire × breed of dam interaction did not approach significance ($P < 0.05$) for any trait examined, the between sires mean squares are unlikely to suffer from bias from this source (see Section 3.3.2.1). This result would also suggest that selection within sire breeds may be made without reference to the breed of dam to be used. This result is largely in agreement with the report of Bowman and Broadbent (1966), although they suggested that when ewe breeds differed widely in mature size such an interaction may become important.

Table 4.6 Least squares means and fitted constants for carcass composition adjusted to a constant percentage subcutaneous fat (11.3%) in the side

	Slaughter age (days)	Slaughter weight (kg)	Side weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio
Mean	173.61	39.24	8.33	55.58	15.98	26.94	3.52
Sire breed	**	**	***	***	***	**	***
Dorset Down	-4.53±3.46^{ab}	-1.00±0.27^{a}	-0.29±0.07^{a}	-0.26±0.14^{a}	-0.12±0.09^{a}	0.37±0.14^{a}	0.01±0.02^{a}
Ile de France	0.73±3.31^{bc}	-0.83±0.26^{a}	-0.14±0.06^{ab}	-0.25±0.13^{a}	-0.11±0.09^{a}	0.36±0.13^{a}	0.00±0.02^{a}
Oldenburg	10.01±3.45^{cd}	0.61±0.27^{b}	-0.12±0.07^{ab}	-0.20±0.14^{a}	0.41±0.09^{b}	-0.30±0.14^{b}	-0.10±0.02^{a}
Oxford	-13.92±3.31^{a}	0.15±0.26^{b}	0.02±0.06^{b}	-0.46±0.13^{a}	0.68±0.09^{b}	-0.24±0.13^{b}	-0.17±0.02^{a}
Suffolk	-5.70±3.25^{ab}	0.26±0.26^{b}	0.05±0.06^{b}	-0.68±0.13^{a}	0.28±0.09^{b}	0.40±0.13^{a}	-0.10±0.02^{a}
Texel	13.41±3.19^{d}	0.82±0.25^{b}	0.48±0.06^{c}	1.84±0.13^{b}	-1.13±0.09^{c}	-0.60±0.13^{b}	0.36±0.02^{b}
Dam breed	***	NS	NS	***	***	NS	***
Dam Line	6.37±1.53	-0.04±0.03	-0.23±0.12	0.23±0.06	-0.34±0.04	0.11±0.06	0.08±0.01
Greyface	-6.37±1.53	0.04±0.03	0.23±0.12	-0.23±0.06	0.34±0.04	-0.11±0.06	-0.08±0.01

Table 4.6 continued Comparison at a constant level of subcutaneous fat in the side

	Lean:fat ratio	% Intermuscular fat	% KKCF	Subcutaneous: intermuscular fat	Lean weight/ day of age (g/day)
Mean	2.20	11.04	3.51	1.13	60.05
Sire breed	**	***	NS	***	**
Dorset Down	-0.02±0.02^{ab}	0.34±0.11^{a}	0.03±0.06	-0.04±0.01^{a}	-2.57±1.34^{ab}
Ile de France	-0.06±0.02^{a}	0.41±0.11^{a}	-0.05±0.06	-0.04±0.01^{a}	-0.87±1.28^{ab}
Oldenburg	-0.01±0.02^{ab}	-0.24±0.11^{b}	-0.05±0.06	0.03±0.01^{a}	-4.72±1.34 ^{a}
Oxford	-0.02±0.02^{ab}	-0.12±0.11^{b}	-0.12±0.06	0.02±0.01^{a}	5.62±1.28 ^{c}
Suffolk	-0.07±0.02^{a}	0.42±0.11^{a}	-0.02±0.06	-0.04±0.01^{a}	2.48±1.26^{bc}
Texel	0.18±0.02^{b}	-0.81±0.10^{c}	0.21±0.06	0.08±0.01^{b}	0.07±1.24^{ab}
Dam breed	NS	NS	***	*	***
Dam Line	-0.01±0.01	-0.09±0.05	0.19±0.03	0.01±0.01	2.97±0.59
Greyface	0.01±0.01	0.09±0.05	-0.19±0.03	-0.01±0.01	-2.97±0.59

Table 4.6 continued Comparison at a constant level of subcutaneous fat in the side

	Slaughter age (days)	Slaughter weight (kg)	Side weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio
Year	***	***	***	*	***	**	***
1973	5.37±2.47[a]	-0.34±0.20[a]	-0.27±0.05[a]	0.21±0.10[a]	-0.45±0.07[a]	0.40±0.10[a]	0.11±0.02[a]
1974	-24.90±2.56[b]	-1.52±0.20[b]	0.04±0.05[b]	0.07±0.10[a]	0.25±0.07[b]	-0.43±0.10[b]	-0.05±0.02[b]
1975	19.53±2.54[c]	1.86±0.20[c]	0.23±0.05[c]	-0.29±0.10[b]	0.20±0.07[b]	0.03±0.10[a]	-0.06±0.02[b]
Ewe age (years)	***	NS	**	NS	**	NS	*
One	36.74±4.83[a]	-0.27±0.09	-0.31±0.39[a]	0.15±0.20	-0.34±0.13[a]	0.17±0.19	0.10±0.03[a]
Two	-10.21±2.80[b]	-0.00±0.05	0.06±0.22[ab]	0.05±0.11	0.23±0.08[b]	-0.24±0.11	-0.05±0.02[b]
Three	-26.53±3.98[c]	0.27±0.08	0.25±0.32[b]	-0.20±0.16	0.11±0.11[b]	0.07±0.16	-0.04±0.03[b]
Sex	NS	**	***	NS	*	NS	*
Female	0.16±2.20	-0.63±0.20	-0.20±0.05	0.07±0.10	-0.16±0.07	0.13±0.10	0.04±0.02
Wether	-0.16±2.20	0.63±0.20	0.20±0.05	-0.07±0.10	0.16±0.07	-0.13±0.10	-0.04±0.02

Table 4.6 continued Comparison at a constant level of subcutaneous fat in the side

	Lean:fat ratio	% Intermuscular fat	% KKCF	Subcutaneous: intermuscular fat	Lean weight/ day of age (g/day)
Year	**	*	NS	***	***
1973	-0.05±0.02[a]	0.02±0.08[ab]	0.37±0.04	-0.01±0.01[a]	-5.74±0.96[a]
1974	0.03±0.02[b]	-0.27±0.08[a]	-0.16±0.04	0.04±0.01[b]	10.69±0.99[b]
1975	0.02±0.02[b]	0.25±0.08[b]	-0.22±0.04	-0.03±0.01[a]	-4.95±0.99[a]
Ewe age (years)	NS	NS	NS	NS	***
One	-0.03±0.03	0.01±0.15	0.16±0.08	-0.00±0.02	-17.45±1.85[a]
Two	0.03±0.02	-0.15±0.09	-0.09±0.05	0.02±0.01	4.37±1.07[b]
Three	0.00±0.03	0.14±0.13	-0.08±0.07	-0.01±0.01	13.09±1.53[c]
Sex	NS	NS	***	NS	***
Female	-0.01±0.01	-0.02±0.08	0.16±0.04	0.00±0.01	-2.54±0.74
Wether	0.01±0.01	0.02±0.08	-0.16±0.04	0.00±0.01	2.54±0.74

Table 4.6 continued Comparison at a constant level of subcutaneous fat in the side

	Slaughter age (days)	Slaughter weight (kg)	Side weight (kg)	% Lean	% Bone	% Fat	Lean:bone ratio
Rearing type	***	***	***	NS	NS	NS	NS
Single	-36.15±3.44[a]	0.26±0.07[a]	-0.13±0.27[a]	-0.15±0.14	0.15±0.09	-0.03±0.14	-0.04±0.02
Twin	-10.61±2.83[b]	-0.25±0.05[b]	-1.05±0.23[b]	0.11±0.12	-0.03±0.08	-0.13±0.11	0.01±0.02
Triplet	46.77±4.50[c]	-0.01±0.09[ab]	1.19±0.36[c]	0.04±0.18	-0.12±0.12	0.16±0.18	0.03±0.03
Regression on:							
Birth date	NS	NS	NS	NS	NS	NS	NS
	0.30±0.24	-0.04±0.02	-0.02±0.01	-0.02±0.01	0.01±0.01	0.01±0.01	-0.002±0.002
% Subcutaneous fat	***	***	***	***	***	***	***
	7.30±0.88	0.82±0.08	0.27±0.02	-1.10±0.04	-0.45±0.03	1.57±0.04	0.03±0.01

Table 4.6 continued Comparison at a constant level of subcutaneous fat in the side

	Lean:fat ratio	% Intermuscular fat	% KKCF	Subcutaneous: intermuscular fat	Lean weight/ day of age (g/day)
Rearing type	NS	NS	***	NS	***
Single	-0.03±0.03	0.22±0.11	-0.25±0.06[a]	-0.02±0.01	17.09±1.32[a]
Twin	0.03±0.02	0.02±0.09	-0.15±0.05[a]	-0.00±0.01	-1.03±1.09[b]
Triplet	0.00±0.03	-0.24±0.14	0.40±0.08[b]	0.03±0.02	-16.05±1.73[c]
Regression on:					
Birth date	NS	NS	*	NS	*
	-0.002±0.002	-0.002±0.008	0.01±0.004	0.001±0.001	-0.26±0.09
% Subcutaneous fat	***	***	***	***	***
	-0.18±0.006	0.37±0.03	0.20±0.02	0.05±0.004	-1.67±0.30

4.4.2 Interaction terms

It is usual to interpret the interaction of breed of sire by year in terms of a genotype × environment interaction in which different years represent different nutritional or climatic environments. Such an interpretation would not be entirely valid in this work as different sires were used in each year and thus sampling variation within breeds may also be implicated. In this experiment only pre-weaning growth traits were affected by this interaction. It was not possible to classify years as 'good' or 'bad' according to the mean level of performance in that year and also demonstrate that certain breeds showed improved performance relative to other breeds in 'good' years.

The interaction of breed of sire and breed of dam may be interpreted as the specific combining ability of a cross. Vesely, Kozub and Peters (1977) considered that specific combining ability among the most common mutton and range breeds of Canada was unlikely to be important in crossbreeding experiments and suggested that such a result would also hold for crosses amongst European breeds. The lack of significant interactions between sire and dam breeds lends support to this conclusion.

The absence of significant sire breed by slaughter group interactions is in agreement with the results of More O'Ferrall and Timon (1977b). Timon (1975) reported that there was evidence to suggest that the Texel lamb grew faster than the Suffolk as they approached heavier body weights (circa 45.5 kg). The interaction was not significant however ($P > 0.05$). This result was not supported

by this experiment. However, the upper slaughter weight was lower than that used in the Irish experiment. An examination of the fitted constants for the sire breed by slaughter group interaction did not reveal important deviations for any of the traits analysed. Highly significant breed by slaughter group interactions have been reported by other workers, e.g. Vesely and Peters (1972), but greater ranges of slaughter weight have generally been used in these studies.

4.4.3 Environmental effects

Effects due to ewe age and rearing type may be interpreted as being caused by differences in lamb nutrition, which in turn may be caused by differences in maternal ability or by competition among litter mates. Year effects, particularly those dealing with carcass traits, are more difficult to interpret in purely biological terms since it is always possible that undetected differences in dissection standards may bias the results. However, in the three years in which carcass traits were measured in this experiment some trends were observed. In years of high growth rate from birth to slaughter, side weight (KO%) and lean tissue weight/day of age were increased. Similarly the proportion of lean in the carcass decreased with increasing growth rate and the proportion of total fat and the ratio of subcutaneous fat : intermuscular fat tended to increase. Differences between 1973 and 1974 of 31 days in slaughter age and 46 g/day in ADG between birth and slaughter were associated with differences in side weight of 0.9 kg, 3.3% lean and of 0.45 units in lean : fat ratio (mean lean : fat ratio 2.15). These figures would suggest that in years of high lamb growth rates slaughter weights may need to be reduced if lambs are to be slaughtered at a fixed level of fatness.

The increases in lamb liveweight at birth and subsequent ages with increasing age of ewe are in keeping with results presented by Yalcin and Bichard (1964).

According to the model proposed by Dickinson, Hancock, Howell, Taylor and Wiener (1962) twins and triplets are expected to be 78% and 62% respectively of the mean weight of singles at birth. Figures presented in this experiment closely approach this prediction. Subsequent growth performance was dependent upon rearing type and the relative performance of the different birth-rearing type groups was in general agreement with the result of Olson, Dickerson and Glimp (1976). Although the data demonstrated a tendency for the growth rates of twins and triplets (however reared) to approach those of single lambs as age increased they did not demonstrate an increase in the growth rate of twins above that of singles as shown by Olson *et al* (1976). Similarly the contention of Dickerson, Glimp, Tunna and Gregory (1972) that birth-rearing type differences in weight at 10 weeks are relatively unchanged at later ages could not be demonstrated in this experiment.

The progressive effects of increasing ewe age or litter size upon carcass composition were not as clear as the effects upon liveweight growth traits. This may have been a result of small sample sizes or of differences in environment experienced by lambs slaughtered at widely different ages. Adjustment for side weight removed or reduced the effects of ewe age and rearing type upon many carcass traits.

Sex differences in growth and carcass composition were in general agreement with results published by Seebeck (1966), Fourie *et al* (1970).

The interpretation of the date of birth effect is complicated and may involve aspects of the nutritional and reproductive history of the dam as well as the effects of competition between lambs of different ages. In criticism of the present work there is no *a priori* evidence to suggest that linear regression is the best means of correcting for this effect. However a retrospective examination of scatter diagrams did not indicate that the use of linear regression would introduce severe bias. With these reservations in mind it is interesting to note that the effect of date of birth was positive for growth traits to four weeks and negative thereafter. This may suggest that lambs born later in the season may benefit from improved nutrition of the ewe in early lactation but when the lamb begins to graze independently it may suffer from competition with older lambs or be challenged by a high worm burden at an earlier age. Perhaps the most serious economic consequence of a late date of birth is in the greatly increased age at slaughter with no associated benefits in carcass weight or composition.

4.4.4 Breed of Sire

Although the breed of sire effect was not significant for birthweight the ranking of the breeds for this trait was consistent with the report of More O'Ferrall and Timon (1977a). The results of More O'Ferrall and Timon (1977a) differed from the results of this experiment in showing low growth rates for the Oxford Down cross in early life. They also found low growth rates for the Texel relative to the Suffolk as weaning approached but the disadvantage of the Texel cross relative to either the Suffolk, Dorset Down or Ile de France was not so great as reported in this experiment.

More O'Ferrall and Timon (1977a) reported a difference in age at slaughter between the Texel and the Suffolk of 8 days (in favour of the Suffolk). This compares with a difference of 13 days in this experiment. A further difference between the two trials was the much greater slaughter age of the Dorset Down and Ile de France cross lambs relative to the Suffolk and Texel crosses found in the Irish experiment.

The values for % lean, % fat, lean : bone ratio and eye-muscle area are in good agreement with those reported by More O'Ferrall and Timon (1977b) and together with results published by Flamant and Perret (1976) and Osikowski and Borys (1977), they confirm the exceptionally high value for % lean in the carcass of the Texel cross.

The liveweight and lean tissue growth rates of the Oxford, Suffolk, Ile de France and Dorset Down crosses were consistent with estimates based upon mature size (Table 7.17). Values for both traits were lower than expected in the Oldenburg cross. However, liveweight growth rate to a fixed liveweight was lower than expected from the mature size of the Texel whilst lean tissue growth rates were higher.

More O'Ferrall and Timon (1977a) reported a much greater slaughter age for the Dorset Down and Ile de France relative to the Suffolk and Texel, than was found in this experiment. It is possible that sampling variation is responsible for this difference as only four sires of each of these breeds were used in the Irish experiment. However, nutritional effects may also be implicated with the Dorset Down depositing relatively more fat than the Texel and

Suffolk as higher slaughter weights are approached, and thus growing more slowly. This theory would not explain the difference between the Suffolk and the Ile de France. Osikowski and Borys (1977) in a crossing experiment with Merino sheep found that lambs sired by rams of the Ile de France and Texel breeds and reared under semi-intensive conditions did not differ significantly in slaughter age at 46 kg liveweight.

4.4.5 Breed of Dam

The comparative performance of the two dam breeds used in this experiment has been reported in detail by Smith, King, Nicholson, Wolf and Bampton (1979). Figures presented in Tables 4.3 and 4.4 show that the synthetic ABRO Dam Line cross ewe produced lambs which grew more slowly to fixed slaughter weights but which differed only slightly from the Greyface in carcass composition.

CHAPTER 5

GENETIC PARAMETERS OF LAMB GROWTH AND CARCASS COMPOSITION

5.1 RESULTS

5.1.1 Introduction

The degrees of freedom and coefficients of the expectations of the mean squares relevant to each data set are shown in Table 5.1. The residual standard deviations of Model 1 of the previous analysis Table 4.1 represent the phenotypic variances of each trait after adjustment for fixed effects.

5.1.2 Heritability and litter variance

Estimates of the heritability and litter variance for live-weight growth traits and killing-out percent are given in Table 5.2. Heritability values for traits measured prior to 12 weeks of age were non-significant and below 10%. The heritability of ADG birth-slaughter approached significance (0.10 ± 0.06). Killing-out percent was a moderately heritable trait (0.16 ± 07). Estimates of the litter variance were much higher than the heritability estimates of early growth traits. The difference between the estimates of heritability and litter variance for slaughter age and killing-out percent were not so marked.

Carcass dissection traits were more highly heritable than growth traits whilst estimates of the litter variance were lower, Table 5.3. Heritability estimates for percent lean, lean : fat ratio and the percentage of each fat depot in the carcass were highest but estimates for the heritability of lean : bone ratio and subcutaneous : intermuscular fat ratio were not significantly different from zero.

Table 5.1 Degrees of freedom (d.f.) and coefficients of expectation of the mean squares

	Data set	d.f.	Coefficients of expectation of the mean squares		
			Residual	Dam	Sire
			σ^2_R	σ^2_D	σ^2_S
Sires/breed of sire and year	Growth to 12 weeks	72	1	1.85	25.18
	Growth to slaughter	55	1	1.82	23.59
	Carcass dissection	47	1	1.65	14.10
Dams/sires	Growth to 12 weeks	1420	1	1.67	
	Growth to slaughter	1047	1	1.63	
	Carcass dissection	558	1	1.48	
Lambs/dams	Growth to 12 weeks	1045	1		
	Growth to slaughter	739	1		
	Carcass dissection	313	1		

Table 5.2 Estimates of the heritability and litter variance of growth traits

	Heritability (%)	Litter variance (%) §
Birthweight	06 ± 05	39 ± 03
Four week weight	-02 ± 03	39 ± 03
Eight week weight	05 ± 04	38 ± 03
Twelve week weight	04 ± 04	37 ± 03
Average daily gains		
Birth-12 weeks	04 ± 04	38 ± 03
Birth-4 weeks	-00 ± 04	42 ± 03
4-8 weeks	04 ± 04	37 ± 03
8-12 weeks	-03 ± 03	41 ± 03
Birth-slaughter	10 ± 06	33 ± 04
Slaughter age	07 ± 05	21 ± 04
Killing-out percent	16 ± 07	25 ± 04

§ Estimated by $(\sigma^2_D - \sigma^2_S)/(\sigma^2_S + \sigma^2_D + \sigma^2_R)$.

Table 5.3 Estimates of the heritability and litter variance of carcass traits

	Heritability (%)	Litter variance (%)
Tissue in side (%)		
Lean	41 ± 13	10 ± 07
Bone	16 ± 10	25 ± 07
Total fat	37 ± 13	18 ± 06
Subcutaneous fat	36 ± 13	15 ± 07
Intermuscular fat	37 ± 13	04 ± 07
KKCF	37 ± 13	15 ± 07
Lean : bone ratio	13 ± 09	18 ± 07
Lean : fat ratio	46 ± 14	15 ± 07
Subcutaneous : intermuscular fat ratio	12 ± 09	08 ± 07
Subcutaneous fat depth	21 ± 11	17 ± 07
Eye-muscle area	14 ± 10	19 ± 07
Lean weight/day of age	23 ± 11	42 ± 07
Subcutaneous fat score	27 ± 10	10 ± 07
Conformation score	18 ± 12	13 ± 06

Heritability values for subcutaneous fat depth, eye-muscle area and visual carcass assessment scores also tended to be lower than those for percentage lean and percentage fat. The heritability estimate for lean weight/day of age (0.23 ± 0.11) did not differ significantly from the heritability for ADG birth-slaughter (0.24 ± 0.11) estimated from this data set.

5.1.3 Correlations

The phenotypic correlations between weights at different ages were positive and high and declined as the time between measurements increased, Table 5.4. Phenotypic correlation between weight for age traits and previous growth rates were higher than correlations between weight for age and subsequent growth rates. The correlations of liveweight and growth rates with slaughter age were negative and moderately high. Phenotypic correlations between growth traits and killing-out percent were low.

Estimates of the genetic correlations between growth traits were generally unreliable due to low estimates of the sire components of covariance. Some genetic correlations could not be estimated because the sire components were negative.

The phenotypic and genetic correlations between ADG birth-slaughter and lean weight/day of age were positive and high, Table 5.5. The phenotypic correlations of these two traits with carcass traits were generally close to zero. The genetic correlations between lean weight/day of age and carcass traits tended to be stronger than those between ADG birth-slaughter and carcass traits. Although standard errors of the genetic correlations were high they suggested that the genetic relationships between growth rates to a

Table 5.4 Correlations[#] (× 100) amongst liveweight growth traits

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Birthweight	(1)		55	49	43	26	23	19	10	28	-30	03
4 week weight	(2)	-[†]		83	74	67	93	26	18	59	-57	22
8 week weight	(3)	-11±69	-		88	84	76	76	18	73	-67	28
12 week weight	(4)	22±58	-	114±15		68	68	65	63	79	-73	26
ADG birth-12 weeks	(5)	00±62	-	120±20	98±03		68	66	66	79	-72	28
ADG birth-4 weeks	(6)	-	-		-	-	-	23	17	58	-54	24
ADG 4-8 weeks	(7)	-27±67	-	132±32	157±54	168±60			11	56	-50	23
ADG 8-12 weeks	(8)	-	-		-	-	-	-		45	-40	09
ADG birth-slaughter	(9)	-44±96	82±177	65±25	71±21	77±15	73±41	-	-		-88	29
Slaughter age	(10)	88±141	-31±115	-54±35	-44±40	-57±36	-66±50	-	-	-98±05		-07
Killing-out (%)	(11)	-72±88	-03±112	14±39	-03±43	05±36	32±50	-	-	53±21	-52±31	

[#] Phenotypic correlations above the diagonal, genetic correlations below.

[†] Values not estimable because of negative sire components.

Table 5.5 Correlations[#] (× 100) between some carcass traits and ADG birth to slaughter

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
ADG Birth-slaughter	(1)		08	03	-07	03	-07	-27	-00	04	08	08	03	94	-00	20
% Lean	(2)	15±29		41	-93	-83	-77	-60	22	88	-26	-61	09	21	-47	-38
% Bone	(3)	80±37	67±22		-71	-64	-47	-54	-79	63	-34	-50	-26	-01	-43	-52
% Total fat	(4)	-32±29	-98±02	-82±12		91	79	68	14	-93	34	68	04	-15	53	49
% Subcutaneous fat	(5)	-47±41	-98±07	-31±42	92±06		50	50	12	-83	67	69	08	-05	53	52
% Intermuscular fat	(6)	-27±24	-75±09	-77±21	83±08	57±19		38	-01	-74	-29	43	-00	-16	33	33
% KKCF	(7)	-27±27	-67±14	-84±14	77±10	74±19	35±18		19	-62	23	42	-01	-28	32	26
Lean:bone ratio	(8)	-89±39	36±31	-45±26	-15±31	-64±46	00±26	15±25		-09	17	12	33	13	14	28
Lean : fat ratio	(9)	28±26	94±03	81±12	-97±02	-88±09	-84±07	-70±09	12±24		-35	-57	-05	13	-50	-48
Subcutaneous: intermuscular fat ratio	(10)	-57±39	-58±26	41±44	38±25	31±33	-60±21	58±21	-119±47	-34±20		37	10	07	33	32
Subcutaneous fat depth	(11)	-30±39	-80±15	-14±45	74±16	80±14	50±17	55±23	-61±42	-64±18	18±34		05	04	45	40
Eye-muscle area	(12)	38±31	53±29	-12±44	-42±33	-56±41	-07±26	-56±30	64±30	38±29	-54±38	-47±39		44	13	29
Lean weight/ day of age	(13)	95±03	41±24	93±30	-56±22	-75±32	-42±20	-33±20	-75±32	55±23	-80±07	-47±32	49±24		-01	21
Subcutaneous fat score	(14)	-23±29	-85±12	-59±19	85±10	78±18	39±18	73±13	-30±28	-81±09	82±33	73±20	-19±32	-34±21		64
Conformation score	(15)	07±32	-79±18	-60±20	81±14	66±30	46±26	49±19	-21±33	-77±11	26±32	44±36	40±38	-16±25	100±07	

Phenotypic correlations above the diagonal, genetic correlations below.

constant liveweight and percentage lean, percentage bone and lean : fat ratio were positive whilst the relationships with fat percentage and lean : bone ratio were negative. The percentage of lean in the carcass was positively related to percent bone, lean : bone ratio, lean : fat ratio and eye-muscle area and negatively related to the proportion of each fat depot in the carcass. The genetic correlations between percentage lean or lean : bone ratio and the ratio of subcutaneous : intermuscular fat were negative.

The phenotypic correlations between subcutaneous fat depth and percentage carcass composition were moderately high but the phenotypic relationships between eye-muscle area and carcass traits were low. The genetic correlations of both subcutaneous fat depth and eye-muscle area with carcass composition were moderately high. Subjective assessment scores of subcutaneous fat cover and carcass conformation were positively correlated to carcass fatness.

5.2 DISCUSSION

That the sire × dam breed interaction was not significant for any of the traits examined (Section 4.2.1) suggests that corrections for dam breed could be made by fitting dam breed as a covariate in this analysis without fear of introducing bias into the estimates of genetic parameters.

The low heritability estimates of early liveweight growth traits are consistent with previously published estimates for Down cross sheep (Section 2.5.1). Using Table 1 of Dickerson (1959) the litter variances of Table 5.2 and 5.3 can be seen to contain one quarter of the variance due to dominance deviations from average gene effects, total variance from genetic variation in direct maternal effects, covariance between total genetic deviations in the transmitted and the direct maternal effects, all variance arising from common environment and small proportions of the variance due to epistasis. The variance components may also be used to give $(\sigma^2_R - \sigma^2_S)/(\sigma^2_S + \sigma^2_D + \sigma^2_R)$ which contains three quarters of the variance from dominance deviations, much of the variance due to epistasis and all variance due to environmental effects which occur whether the individuals are related or not. It is unfortunately impossible to use this data to determine which of the elements described above are most important in increasing the phenotypic variance. The use of constant slaughter weight end-points made it impossible to estimate the heritability of daily gain between weaning and slaughter and there is therefore little evidence to indicate a rise in the heritability of growth traits with increasing age. In common with previous evidence of the low heritability of early growth in Down

cross sheep these results would support investigations into methods of increasing heritability by reducing environmental sources of variation. Owen, Brook, Read, Steane and Hill (1978) have found higher effective heritabilities for weight for age for artificially reared lambs and their technique may provide a useful method of selection.

The number of records available for analysis was too small to allow the estimation of heritability within individual breeds of sire. Breed differences in heritability estimates may exist and it would be unreasonable to extend the conclusions reached for U.K. Down breeds to the three imported breeds without further investigation. A recent analysis of large numbers of records MLC recorded flock data (P. Bampton, personal communication) produced heritability estimates of 0.19 ± 0.03 for 8 week weight in pure bred Dorset Down and Suffolk flocks.

The heritability estimates of percentage carcass composition and lean : bone ratio were in good agreement with those presented by Botkin, Field, Riley, Nolan and Roehrkasse (1969). Heritability estimates for subcutaneous fat depth and eye-muscle area tended to be lower than previously published results (Botkin *et al*, 1969; Bowman and Hendy, 1972; Cotterill and Roberts, 1976). These results indicate that genetic selection to change carcass composition at a fixed liveweight should be successful. The results suggest that the ratio of lean : fat is more amenable to selection than the lean : bone or subcutaneous : intermuscular fat ratios. This is an important result in view of the widespread consumer resistance to animal fat and the specific problem of over fatness in the lamb carcass (Kempster, 1979).

Estimates of litter variance for carcass traits were much lower than those for liveweight growth traits. If variance due to dominance and epistasis may be assumed to be small for carcass traits this would suggest that common environmental and maternal effects are relatively unimportant when compared to environmental variation arising from effects affecting all lambs irrespective of their litter of origin.

Although the genetic correlations between ADG birth-slaughter and measures of fatness were low and had large standard errors, their size and sign is in agreement with a summary of estimates from beef cattle experiments with constant slaughter weight end-points (Barlow, 1978). This result is consistent with the idea that faster growth to a fixed weight is related to a larger mature size and thus less mature and leaner animal at slaughter. The unfavourable genetic correlation between growth rate and lean : bone ratio is of some concern. However, the low heritability and phenotypic standard deviation for lean : bone ratio may mean that the correlated response to selection for growth rate may not be severe.

Selection for carcass composition is complicated by the difficulty of estimating the traits of interest in the live animal and thus achieving selection objectives by performance test. The alternative - a progeny test - has the disadvantages of higher cost, lower selection intensity and increased generation interval. Thus the correlations between traits which can be measured in the live animal and its carcass composition are of particular interest. Ultrasonic equipment allows the estimation of subcutaneous fat depth and eye-muscle area in the live animal. The phenotypic correlations of these two traits with carcass composition confirm previously published work

suggesting that subcutaneous fat depth would provide a better prediction of lean percentage than eye-muscle area (e.g. Kempster, Avis, Cuthbertson and Harrington, 1976). However, the ultimate value of ultrasonic techniques will depend upon the correlations between the ultrasonically predicted eye-muscle area or fat depth and carcass traits. The genetic correlations of both eye-muscle area and subcutaneous fat depth measured on the carcass with percentage lean suggest that they may have value for inclusion in a selection index.

CHAPTER 6

ANALYSIS OF THE VARIATION IN TISSUE DISTRIBUTION

6.1 LEAN TISSUE DISTRIBUTION

6.1.1 Effects of genotype and environmental factors

Uncorrected means, standard deviations and coefficients of variation for the percentage distribution of the dissectible lean tissue are given in Table 6.1. Coefficients of variation ranged from 3.3% for the higher-priced joints to 15.2% and 16.5% for the breast and scrag respectively. In general the coefficient of variation was much lower for joints with a high weight of lean than for joints with low lean weights, but the coefficient of variation for the breast did not fit into this pattern. Comparisons of the standard deviations (Table 6.1) with the residual standard deviations (Table 6.2) indicate that the factors included in the model explained from 10% (scrag) to 21% (breast) of the total variation, and 17% for the prime joints combined.

Least squares means, fitted constants and significance levels for the effects of sire and dam breed, sex, ewe age, rearing type, birth date and lean weight regression are given in Table 6.2. Although year effects on lean tissue distribution were highly significant they have not been included in Table 6.2 because of the difficulty of applying a biological interpretation to this source of variation. Year effects are shown in Appendix 3. The interactions of sire breed × year, dam breed × year and sire breed × dam breed were not significant ($P > 0.05$).

Breed of sire explained a significant proportion of the variation in lean tissue distribution for all individual joints except

Table 6.1 Means, standard deviations (s.d.) and coefficients of variation (CV%) for the percentage of total dissectible lean tissue in each standard joint (unadjusted data)

Percentage of total carcass lean in:	Mean	s.d.	CV%
Leg#	29.87	1.28	4.3
Chump#	7.94	0.74	9.3
Loin#	10.66	1.08	10.1
Best-end neck#	6.50	0.58	8.9
Breast	9.28	1.41	15.2
Middle neck	12.52	0.81	6.5
Scrag	2.43	0.40	16.5
Shoulder	20.79	1.11	5.3
Higher-priced joints	54.98	1.79	3.3

Higher-priced joint.

Table 6.2 Least squares means and fitted constants for the distribution of dissectible lean

	No.	Percentage of total carcass lean found in the								
		Leg	Chump	Loin	Best-end neck	Breast	Middle-neck	Shoulder	Scrag	Higher-priced joints
Mean	956	29.80	7.90	10.61	6.47	9.39	12.60	20.80	2.43	54.78
Breed of Sire		*	NS	* *	* *	*	* *	* *	NS	NS
Dorset Down	154	0.34±0.09^{a}	0.03±0.05	0.19±0.08^{ab}	0.20±0.04^{a}	0.28±0.09^{a}	-0.07±0.06	-0.34±0.08^{a}	0.06±0.03	0.08±0.12
Ile de France	163	0.38±0.09^{c}	0.02±0.05	-0.05±0.08^{ab}	-0.05±0.04^{b}	-0.42±0.09^{b}	-0.02±0.06	0.16±0.08^{bc}	-0.02±0.03	0.30±0.12
Oldenburg	138	-0.08±0.09^{ab}	-0.01±0.05	-0.22±0.08^{bc}	-0.02±0.04^{b}	0.15±0.10^{a}	0.17±0.06	0.01±0.08^{ab}	0.00±0.03	-0.34±0.12
Oxford	156	-0.01±0.09^{ab}	0.07±0.05	0.16±0.08^{ab}	0.07±0.04^{ab}	-0.09±0.09^{ab}	0.09±0.06	-0.20±0.08^{ab}	-0.10±0.03	0.30±0.12
Suffolk	158	-0.16±0.09^{ab}	-0.08±0.05	0.34±0.08^{a}	-0.00±0.04^{b}	0.16±0.09^{ab}	0.08±0.05	-0.03±0.07^{ab}	0.01±0.03	0.10±0.12
Texel	187	0.21±0.09^{bc}	-0.02±0.05	-0.43±0.08^{c}	-0.20±0.04	0.24±0.09^{a}	-0.24±0.05^{a}	0.39±0.07^{c}	0.04±0.03	-0.44±0.12
Breed of Dam		NS	NS	NS	NS	NS	NS	NS	NS	NS
ABRO Dam Line	514	-0.03±0.04	-0.02±0.02	0.02±0.03	0.03±0.02	-0.08±0.04	0.03±0.03	0.06±0.03	-0.01±0.01	0.01±0.05
Greyface	442	0.03±0.04	0.02±0.02	-0.02±0.03	-0.03±0.02	0.08±0.04	-0.03±0.03	-0.06±0.03	0.01±0.01	-0.01±0.05
Sex		NS	* *	NS	NS	*	NS	* **	* **	*
Female	502	0.00±0.06	0.10±0.04	0.08±0.05	0.03±0.03	0.13±0.06	-0.05±0.04	-0.22±0.05	-0.07±0.02	0.22±0.09
Male	454	-0.00±0.06	-0.10±0.04	-0.08±0.05	-0.03±0.03	-0.13±0.06	0.05±0.04	0.22±0.05	0.07±0.02	-0.22±0.09

Table 6.2 continued Distribution of lean tissue

	No.	Percentage of total carcass lean found in the								
		Leg	Chump	Loin	Best-end neck	Breast	Middle-neck	Shoulder	Scrag	Higher-priced joints
Ewe age (years)		*	NS	NS	* *	NS	NS	*	NS	NS
One	88	0.29±0.13[d]	0.18±0.08	-0.13±0.11	-0.16±0.06[d]	0.24±0.13	-0.13±0.08	-0.28±0.11[d]	-0.01±0.04	0.18±0.17
Two	710	0.01±0.07[e]	-0.05±0.04	0.05±0.06	-0.03±0.03[e]	-0.07±0.08	0.01±0.05	0.11±0.06[e]	-0.03±0.02	-0.02±0.10
Three	158	-0.30±0.10[f]	-0.14±0.06	0.08±0.09	0.19±0.05[f]	-0.17±0.11	0.12±0.07	0.17±0.09[e]	0.03±0.03	-0.16±0.14
Rearing type		NS	NS	NS	*	*	*	* *	NS	NS
Single	181	-0.11±0.09	-0.09±0.05	0.07±0.08	0.11±0.04[k]	-0.24±0.09[g]	0.04±0.06[g]	0.19±0.08[g]	0.04±0.03	-0.02±0.12
Twin	718	0.14±0.07	0.08±0.04	0.01±0.06	-0.01±0.03[g]	0.12±0.08[h]	-0.14±0.05[h]	-0.19±0.06[h]	-0.01±0.02	0.21±0.10
Triplet	57	-0.02±0.12	0.01±0.07	-0.08±0.10	-0.09±0.06[g]	0.12±0.12[gh]	0.10±0.08[g]	0.00±0.10[gh]	-0.03±0.04	-0.18±0.15
Regression on date of birth (× 100)		1.15±0.63	-0.71±0.38	0.53±0.54	-0.71±0.30	1.17±0.65	-0.85±0.40	-0.34±0.54	-0.24±0.02	0.26±0.83
Regression on total lean in the side (kg)		-0.34±0.13	-0.00±0.08	0.11±0.11	-0.11±0.06	0.87±0.13	-0.17±0.08	-0.44±0.11	0.09±0.04	-0.35±0.18
Residual standard deviation		1.05	0.65	0.91	0.51	1.11	0.71	0.94	0.36	1.49

the chump and scrag. However, the maximum differences between breeds for the percentage lean in each joint never exceeded 0.77 percentage points. The breed of sire did not have a significant effect on the percentage lean in the higher-priced joints. The breed of dam effect was not significant for any of the traits considered.

Small differences in lean tissue distribution were observed between the sexes with females having a higher proportion of lean in the chump, breast and higher-priced joints and a lower proportion in the shoulder and scrag than wethers.

Age of ewe significantly affected percentage lean in the leg, best-end neck and shoulder joints. The progeny of older ewes tended to have a higher percentage lean in the best-end neck and shoulder and a lower percentage in the leg. Trends with rearing type were not so clearly defined, lambs from multiple litters having a lower percentage of lean in the best-end neck and shoulder and a higher percentage in the breast.

The regression of the percentage lean in each joint on weight of total lean showed that lean in the leg, middle neck, shoulder and in the higher-priced joints was a declining proportion of an increasing lean mass, whilst the lean in the breast and scrag constituted an increasing proportion.

6.1.2 Heritability and correlations

The degrees of freedom and the coefficients of the components of variance in the expectations of the mean squares for this analysis are given in Table 6.3. The heritability estimates were of moderate size for most traits with a particularly high value (0.65 ± 0.16) for the percentage of carcass lean found in the higher-priced joints (Table 6.4).

Table 6.3 Degrees of freedom (d.f.) and coefficients of the components of variance# in the expectation of the mean squares

Mean square	d.f.	Coefficients of expectation of the mean squares		
		Residual	Dam	Sire
		σ^2_R	σ^2_D	σ^2_S
Sires/breed of sire and year	47	1	1.65	14.07
Dams/sires	557	1	1.48	
Lambs/dams	313	1		

σ^2_S = sire component,

σ^2_D = dam component,

σ^2_R = residual component.

Table 6.4 Heritability estimates for lean tissue distribution

Percentage of total carcass lean in:	Heritability
Leg#	0.21 ± 0.10
Chump#	0.28 ± 0.11
Loin#	0.46 ± 0.14
Best-end neck#	0.07 ± 0.08
Breast	0.35 ± 0.12
Middle neck	0.15 ± 0.09
Shoulder	0.33 ± 0.12
Scrag	0.28 ± 0.11
Higher-priced joints	0.65 ± 0.15

Higher-priced joint.

Estimates of the phenotypic correlations were generally close to zero (Table 6.5) but a number of genetic correlations were moderately high and significant ($P < 0.05$). With the exception of correlations of the leg and chump with the best-end neck genetic correlations between percentage lean in the individual higher-priced joints were positive and in the range 0 - 0.7. The lean distribution traits in the remaining joints also formed a genetically intercorrelated group. Correlations between members of the higher-priced joint group and remaining joints were negative and high. The standard errors of the genetic correlations were variable and the standard errors attached to correlation coefficients close to $\pm$ 1.0 are unreliable and likely to be unrealistically low due to the method of estimation.

Table 6.5 Phenotypic[#] and genetic correlations for lean tissue distribution

Percentage of total carcass lean found in the:		1	2	3	4	5	6	7	8	9	10	11
Leg	(1)		0.08	-0.16	-0.15	-0.44	-0.25	-0.16	-0.25	0.60	-0.09	-0.10
Chump	(2)	0.65±0.28		-0.24	-0.06	-0.17	-0.10	-0.18	-0.13	0.32	-0.14	-0.17
Loin	(3)	0.49±0.29	0.04±0.23		0.22	-0.18	-0.25	-0.37	-0.08	0.50	0.06	0.05
Best-end neck	(4)	-0.25±0.46	-0.54±0.40	1.00±0.35		-0.23	-0.19	-0.11	-0.02	0.33	0.21	0.24
Breast	(5)	-0.66±0.20	-0.38±0.21	-0.73±0.14	-0.17±0.31		-0.08	-0.25	0.06	-0.58	-0.12	-0.11
Middle neck	(6)	-0.57±0.31	-0.18±0.29	-0.27±0.22	-0.58±0.37	0.14±0.24		0.07	0.04	0.44	0.00	-0.00
Shoulder	(7)	-0.47±0.25	-0.59±0.19	-0.68±0.13	-0.50±0.32	0.29±0.20	0.47±0.22		-0.00	-0.47	0.19	0.20
Scrag	(8)	-0.83±0.21	0.05±0.23	-0.57±0.18	0.30±0.33	0.47±0.18	-0.09±0.23	0.45±0.17		-0.30	-0.03	-0.02
Higher-priced joints	(9)	0.83±0.12	0.51±0.15	0.87±0.07	0.40±0.24	-0.80±0.07	-0.49±0.15	-0.78±0.08	-0.60±0.11		-0.02	-0.03
ADG birth-slaughter	(10)	-0.41±0.28	-0.61±0.23	0.87±0.21	0.40±0.36	-0.35±0.23	0.01±0.31	0.04±0.24	0.04±0.25	0.17±0.20		0.97
Lean weight/day of age	(11)	-0.36±0.39	-0.82±0.31	0.95±0.30	0.72±0.44	-0.37±0.31	-0.20±0.41	0.05±0.32	-0.02±0.32	0.22±0.27	0.96±0.03	

[#] Phenotypic correlations above the diagonal, genetic correlations below.

6.1.3 Discussion

The lambs included in this study were slaughtered at very roughly 50% of their expected mature weight (see Table 7.17). The values presented for the regressions of percentage lean in the individual joints on total lean weight support the conclusion of Taylor *et al* (1980) that only minor changes in lean distribution occur during this stage of lean growth. The patterns of differential growth of the lean tissue described by these regressions were similar to previously published results (see review, Section 2.3.2). The decline in percent lean in the leg relative to total lean mass is in agreement with results presented by Seebeck (1968) and Jackson (1969). Lohse *et al* (1971) and Jury *et al* (1977) found that muscles surrounding the spinal column formed a constant proportion of total muscle mass in later stages of growth. This spinal muscle group is approximated in this study by lean in the chump, loin and best-end neck which all gave regressions on lean weight which were not significantly different from zero ($P > 0.05$). The percentage lean in the breast increased with total muscle weight. Such an increase might be expected since the breast joint includes a major proportion of the abdominal muscle which increases with rumen development and increasing intakes of roughage (Berg and Butterfield, 1976). Similarly the negative regressions for percent lean in the shoulder and prime joints are in agreement with the differential growth patterns reported by Seebeck (1968), Lohse *et al.*, (1971) and Jury *et al.*, (1977).

The breed differences in lean tissue distribution (Table 6.2) are of similar size to those reported by Seebeck (1968) and Jury *et al.*, (1977). Differences in percent lean in the higher-priced joints

are lower than those found by Taylor *et al.*, (1980) and did not reach significance in this work. Kempster and Cuthbertson (1977) and Croston *et al.* (1979) did not find large differences between Down breeds for this trait. It may be possible to attribute commercial importance to small but significance differences in lean tissue distribution, especially where large numbers of carcasses are traded. However, most emphasis must ultimately be placed upon the larger differences between breeds in the weight of total lean produced. Furthermore variations in the cutting methods used by butchers may alter the importance of the biological differences, demonstrated by using standard jointing procedures.

The breed differences in lean tissue distribution do not relate to the developmental patterns of lean tissue distribution in a manner which is entirely consistent with breed ranking for mature size (Table 7.17). Berg, Andersen and Liboriussen (1978) considered that differences between cattle breeds in muscle weight distribution at constant weight of total muscle could not be entirely explained in terms of differences in maturity. They considered that breed differences in muscle-weight distribution "were probably a reflection of a combination of different maturity status and minor functional influences resulting from differences in size, shape, skeletal dimensions and muscling". The results of this study would suggest that variation between breeds of sheep for lean tissue distribution parallel the results of Berg *et al.* (1978) for cattle. However the relationship between deviations which do not relate to the stage of maturity of each breed at the time of comparison and functional causes can be no more than speculation.

The higher proportion of total lean in the higher-priced joints of females and in the shoulder and scrag of the wether lambs is in keeping with the analyses of Lohse (1973), Jury *et al.* (1977) and Taylor *et al.* (1980) who related their findings to the functional role of muscle differentiation in sexual development. These results also support the conclusion of Jury *et al.* (1977) that castration does not entirely remove the characteristic male muscle development in the neck and shoulder regions.

The effects of ewe age and rearing type may be interpreted as being due to differences in lean tissue growth rate, lambs born to older ewes or reared in smaller litters having higher rates of lean tissue growth. However, the patterns of significance were different for the two factors, which may be due in part to the small number of triplet lambs and lambs reared by one year-old ewes, and in part to a difference in magnitude of the effect on growth rate (rearing type having a greater effect on lean tissue growth rate than ewe age). An increase in growth rate tended to reduce the percentage of total lean in the leg and breast and increase the percentage in the best-end neck and shoulder. These results are not comparable with the effects of growth rate recorded by Boccard and Dumont (1973) and Murray and Slezacek (1975).

The heritability estimates (Table 6.4) indicate that selection to change lean tissue distribution would be possible. In general, however, where heritability estimates were highest, the coefficients of variation were low. This was particularly noticeable for the higher-priced joints. Dissection errors may make large contributions to variation in the percentage of total lean in small joints, thus

explaining the association between size of joint and coefficient of variation. The net effect of these considerations would be that the expected response to selection would be small. In the absence of suitable predictors of lean tissue distribution it is unlikely that selection for these traits is a worthwhile objective.

It may be possible to change the mature size of domestic livestock and increase the proportion of total lean found in the higher-priced joints as a correlated response to selection for growth rate (Berg *et al.*, 1978). The genetic correlation between growth rate and percentage lean in the prime joints (0.18 ± 0.20, Table 6.5) is in good agreement with a value of 0.24 ± 0.18 for a similar trait in beef cattle (Andersen, 1978). However, the genetic correlations between growth rate and percentage lean in the individual higher-priced joints did not conform to the patterns of development indicated by the regression coefficients on total lean weight (Table 6.2), so that the effect of selection may be less clear than expected.

The interpretation of the correlation matrix is complicated by the statistical adjustment to constant total lean weight. At constant total lean weight an increase in the proportion of lean found in a given joint implies a reduction in the remainder. This may be regarded as a negative environmental correlation which will tend to reduce the value of the phenotypic correlation but leave the genetic correlation unaffected. A comparison of correlations estimated before and after adjustment suggested that this was the case and therefore the genetic correlations are unbiased by the statistical adjustment.

Few of the genetic correlations presented support the proposal of Guttman and Guttman (1965) that "two features that are closer to

each other in terms of structural or processual relations should also be closer in the sense of statistical correlation". This is not unexpected as the dissection method used in this study was based upon commercial practices and only a few of the joints (e.g. leg, shoulder, loin plus best-end neck) even approximate to the functional units defined by Fowler (1968). It is clear, however, that selection for lean distribution in favour of any one of the higher-priced joints would give a correlated increase in the percentage lean in the higher-priced joints.

6.2 SUBCUTANEOUS FAT DISTRIBUTION

6.2.1 Effects of genotype and environmental factors

Uncorrected means, standard deviations and coefficients of variation for the percentage distribution of dissectible subcutaneous fat are given in Table 6.6. Coefficient of variation ranged from 16.5% for the chump to 23.1% in the breast with a high value of 40.4% in the scrag. Coefficients of variation did not therefore show as great a range as those for the percentage distribution of dissectible lean, nor was there a clear relationship between the percentage of subcutaneous fat in a joint and the size of the coefficient of variation. Comparisons of the standard deviations (Table 6.6) with the residual standard deviations (Table 6.7) indicate that the model explained from 8.3% (chump) to 15.5% (loin) and 34.6% (leg) of the total variation.

Least squares means, fitted constants and significance levels for the effects of sire and dam breed, sex, ewe age, rearing type, birthdate and regression on weight of subcutaneous fat are given in Table 6.7. Year effects, which were significant for all traits, are given in Appendix 3. The interaction of sire breed × year, sire breed × dam breed and dam breed × year were not significant ($P > 0.05$).

Breed of sire explained a significant proportion of the variation in subcutaneous fat distribution in the leg, best-end neck, shoulder and scrag. The maximum difference recorded between breeds was one of 2.0 percentage points in the proportion of subcutaneous fat in the leg, a difference which represented 8.2% of the mean value for this trait. The Suffolk and Oxford crosses tended to have more of their total subcutaneous fat in the leg and less in the shoulder than the Ile de France and Texel crosses.

Table 6.6 Means, standard deviations (s.d.) and coefficients of variation (CV%) for the percentage of total dissectible subcutaneous fat in each standard joint (unadjusted data)

Percentage of total carcass subcutaneous fat in :	Mean	s.d.	CV%
Leg	24.09	4.22	17.5
Chump	10.21	1.68	16.5
Loin	14.18	2.71	19.1
Breast	14.83	3.42	23.1
Best-end neck	11.54	2.10	18.2
Shoulder	22.33	4.00	17.9
Scrag	2.82	1.14	40.4

Table 6.7 Least squares means and fitted constants for the distribution of dissectible subcutaneous fat

	Number	Percentage of total subcutaneous fat in:						
		Leg	Chump	Loin	Best-end neck	Breast	Shoulder	Scrag
Mean	949	24.04	10.29	14.64	11.82	14.73	21.73	2.76
Breed of sire		**	NS	NS	*	NS	*	**
Dorset Down	154	-0.16±0.25^{abc}	0.04±0.13	-0.26±0.18	0.53±0.15^{a}	-0.08±0.24	-0.17±0.28^{ab}	0.08±0.08^{ab}
Ile de France	162	-1.14±0.25^{c}	0.28±0.12	0.13±0.18	0.27±0.14^{ab}	-0.44±0.24	0.66±0.27^{a}	0.24±0.07^{a}
Oldenburg	136	0.51±0.26^{ab}	-0.41±0.13	-0.03±0.18	-0.12±0.15^{bc}	-0.10±0.25	0.25±0.28^{ab}	-0.11±0.08^{bc}
Oxford	156	0.38±0.25^{ab}	0.12±0.12	0.10±0.18	-0.11±0.14^{bc}	0.41±0.24	-0.76±0.27^{b}	-0.15±0.07^{c}
Suffolk	154	0.83±0.25^{a}	-0.01±0.12	0.42±0.18	-0.35±0.14^{c}	-0.13±0.24	-0.58±0.27^{b}	-0.17±0.07^{c}
Texel	187	-0.43±0.23^{bc}	-0.02±0.11	-0.36±0.17	-0.22±0.13^{bc}	0.33±0.22	0.60±0.25^{a}	0.10±0.07^{ab}
Breed of dam		*	NS	***	*	**	***	NS
ABRO Dam Line	440	-0.28±0.11	0.01±0.06	0.29±0.08	0.13±0.07	0.33±0.11	-0.43±0.13	-0.05±0.04
Greyface	509	0.28±0.11	-0.01±0.06	-0.29±0.08	-0.13±0.07	-0.33±0.11	0.43±0.13	0.05±0.04
Sex		NS	*	NS	NS	*	NS	*
Female	498	-0.14±0.16	0.22±0.09	0.23±0.13	0.11±0.11	-0.40±0.18	0.12±0.20	-0.13±0.06
Male	451	0.14±0.16	-0.22±0.09	-0.23±0.13	-0.11±0.11	0.40±0.18	-0.12±0.20	0.13±0.06

Table 6.7 continued. Distribution of subcutaneous fat

	Percentage of total subcutaneous fat in:						
	Leg	Chump	Loin	Best-end neck	Breast	Shoulder	Scrag
Ewe age (years)	NS	NS	NS	NS	NS	NS	NS
One	-0.44±0.35	0.19±0.18	0.33±0.26	0.21±0.21	0.14±0.34	-0.43±0.39	-0.01±0.11
Two	0.36±0.20	0.09±0.10	-0.25±0.15	-0.10±0.12	-0.09±0.20	0.02±0.23	-0.03±0.06
Three	0.08±0.29	-0.28±0.15	-0.08±0.21	-0.12±0.17	-0.05±0.28	0.41±0.32	0.04±0.09
Rearing type	NS	NS	*	*	*	NS	NS
Single	0.41±0.25	-0.20±0.13	-0.46±0.18[d]	-0.38±0.15[d]	0.64±0.25[d]	-0.01±0.28	-0.01±0.08
Twin	-0.14±0.21	-0.15±0.10	-0.25±0.15[d]	-0.16±0.12[d]	0.26±0.20[d]	0.46±0.23	-0.00±0.07
Triplet	-0.27±0.33	0.35±0.16	0.71±0.24[e]	0.54±0.19[e]	-0.90±0.32[e]	-0.45±0.37	0.01±0.10
Regression on date of birth (× 100)	2.51±1.78	-2.26±0.89	-1.06±1.29	0.85±1.05	1.11±1.73	-0.64±1.98	-0.51±0.56
Regression on total subcutaneous fat in the side (kg)	-4.56±0.53	0.15±0.29	2.68±0.44	1.91±0.36	2.51±0.58	-1.84±0.66	-0.86±0.19
Residual standard deviation	2.76	1.54	2.29	1.88	3.03	3.45	0.99

The progeny of ABRO Dam Line crossbred ewes had significantly less subcutaneous fat in the leg and shoulder and more in the loin, best-end neck and breast than the progeny of the Greyface cross.

Ewe age did not significantly affect the distribution of subcutaneous fat ($P > 0.05$). Single lambs had less subcutaneous fat in the loin and best-end neck and more in the breast than triplet lambs. Female lambs had more subcutaneous fat in the loin and less in the breast than wethers.

The regression of percentage subcutaneous fat in each joint on weight of total subcutaneous fat was significant for all joints except the chump. As the weight of total subcutaneous fat increased the proportion found in the leg, shoulder and scrag decreased and the proportion found in the loin, best-end neck and breast increased.

6.2.2 Heritability and correlations

Degrees of freedom and the coefficients of expectation of the mean squares for this analysis are given in Table 6.8. Heritability estimates in the range 0.21 - 0.31 were found for the percentage of subcutaneous fat in the leg, chump and best-end neck. Heritability estimates for the other traits did not reach significance ($P > 0.05$).

Phenotypic correlations were generally close to zero. Members of the group of higher-priced joints did not form a positively inter-correlated group for subcutaneous fat distribution cf. lean tissue distribution (Section 6.1.2), (Table 6.10).

Table 6.8 Degrees of freedom (d.f.) and coefficients of the components of variance# in the expectation of the mean squares

		Coefficients of expectation of the mean squares		
Mean square	d.f.	Residual σ^2_R	Dam σ^2_D	Sire σ^2_S
Sires/breed of sire and year	48	1	1.64	13.80
Dams/sires	557	1	1.48	
Lambs/dams	313	1		

σ^2_S = sire component,

σ^2_D = dam component,

σ^2_R = residual component.

Table 6.9 Heritability estimates for subcutaneous fat distribution

Percentage of total carcass subcutaneous fat found in :	Heritability
Leg	0.31 ± 0.12
Chump	0.21 ± 0.10
Loin	0.10 ± 0.08
Breast	0.10 ± 0.08
Best-end neck	0.21 ± 0.10
Shoulder	0.08 ± 0.08
Scrag	-0.05 ± 0.05

Table 6.10 Phenotypic# and genetic correlations for subcutaneous fat distribution

Percentage of total carcass subcutaneous fat found in :		1	2	3	4	5	6	7	8
Leg	(1)		-0.18	-0.25	-0.30	-0.32	-0.26	0.03	-0.05
Chump	(2)	0.24±0.32		0.18	-0.20	0.16	-0.28	-0.10	-0.00
Loin	(3)	-0.49±0.35	0.26±0.39		-0.21	0.25	-0.41	-0.11	0.08
Breast	(4)	-0.94±0.29	-0.59±0.34	-0.29±0.47		-0.20	-0.24	-0.10	0.08
Best-end neck	(5)	-0.75±0.19	0.07±0.30	0.66±0.33	0.77±0.43		-0.26	-0.10	-0.10
Shoulder	(6)	-0.12±0.40	-0.92±0.35	-0.24±0.49	0.77±0.66	-0.79±0.35		-0.05	0.00
Scrag	(7)	-	-	-	-	-	-		-0.06
Lean weight/day of age	(8)	0.68±0.24	-0.49±0.26	0.17±0.34	-1.22±0.44	0.03±0.26	-0.20±0.36	-	

Phenotypic correlations above the diagonal, genetic correlations below.

6.2.3 Discussion

The mean values for percent subcutaneous fat in each joint were generally similar to those for percent lean distribution (Table 6.2), although the range in mean values was not so great. The standard deviations before and after analysis were considerably higher than those for lean distribution traits. This greater variability is in keeping with the suggestion that fat depots are more susceptible to variation from unrecorded environmental sources than the lean. It is also possible that difficulty in defining the boundaries of the subcutaneous fat layer may lead to greater variation arising from the dissection.

In general the model explained a similar proportion of the total variation in subcutaneous fat distribution as it did for lean tissue distribution. There seems to be no explanation for the very high value of 34.6% of the total variation in percent subcutaneous fat in the leg explained by the model.

The maximum differences between breeds in subcutaneous fat distribution were not large although in terms of percentage points the differences tended to be equal to or greater than those found for lean distribution. In terms of weight, the maximum difference found of two percentage points represents about 20 g of subcutaneous fat. Larger breed differences would be expected in practice since breeds would be slaughtered when the carcass contained different total amounts of subcutaneous fat. Similarly small differences between breeds were reported by Seebeck (1968). Thompson *et al.* (1979) found no differences between breeds for subcutaneous fat distribution. Berg and Butterfield (1976) have suggested that functional reasons

may be responsible for the small influence of breed upon lean tissue distribution. There seems to be no coherent theory to explain the small variation in subcutaneous fat distribution. Correlations between a breed's rank for percent lean in a given joint and its rank for percent subcutaneous fat in that joint were leg (-0.5), chump and loin (0.6), best-end neck (0.4), breast (0.3) and shoulder (0.8). None of these rank correlations are significant which suggests that differences in subcutaneous fat distribution may be independent of differences in lean tissue distribution.

The effects of growth rate (acting through ewe age and rearing type) on subcutaneous fat distribution were variable, ewe age having no significant effect but the effects of rearing type being much greater than for lean tissue distribution.

The regressions on total subcutaneous fat weight suggested that the patterns of differential growth of this tissue were similar to those of the lean tissue. However, the regression coefficients were much greater than those for lean tissue distribution. This result is in keeping with the subcutaneous fat being a late developing tissue.

The heritability coefficients indicate that additive genetic variation exists for subcutaneous fat distribution. Genetic correlations between lean weight/day of age and distributional traits did not clearly indicate that selection for growth rate would reduce the maturity of the subcutaneous fat depot in a manner which was consistent with differential growth patterns within this tissue.

CHAPTER 7

SERIAL SLAUGHTER TRIAL

7.1 RESULTS

7.1.1 Pre-weaning growth performance

7.1.1.1 Environmental effects

The effect of years on lamb liveweights up to 12 weeks of age (Table 7.1) were not significant ($P > 0.05$). Ewe age significantly affected all preweaning liveweight ($P < 0.001$) with lambs reared by two-year old ewes being lighter than the offspring of three-year olds. Single lambs were heavier than twins ($P < 0.001$), the difference rising from 1 kg at birth to approximately 6 kg at 12 weeks. Female lambs were lighter than wethers at all ages ($P < 0.01$).

The interactions of sex with year, sire breed, dam breed and ewe age, ewe age with year, sire breed and rearing type, rearing type with sire breed and dam breed were non-significant ($P > 0.05$) for all traits. The interaction of year with rearing type was significant for birthweight and 12 week weight.

7.1.1.2 Sire breed

The breed of sire effect did not reach significance ($P > 0.05$) for liveweights at birth, four, eight and 12 weeks (Table 7.1). However, the breeds ranked in a manner fairly consistent with results from the Fixed Slaughterweight Trial (Section 4.2.3). Suffolk and Oxford cross lambs tended to be heavier than the overall breed mean, particularly at later ages. The Southdown, Texel and Oldenburg crosses tended to be lighter than average.

Table 7.1 Pre-weaning growth performance of lambs in the serial slaughter trial

	No.	Birthweight (kg)	4 week weight (kg)	8 week weight (kg)	12 week weight (kg)
Mean	513	4.69	14.34	23.12	31.58
Sire breed		NS	NS	NS	NS
Dorset Down	88	0.01±0.09	-0.05±0.25	-0.30±0.34	-0.17±0.45
Ile de France	43	-0.06±0.16	0.34±0.41	0.21±0.56	-0.13±0.74
Oldenburg	43	-0.25±0.19	-1.08±0.50	-1.22±0.68	-1.13±0.89
Oxford	85	0.07±0.11	0.19±0.29	0.82±0.40	1.27±0.53
Suffolk	84	0.12±0.10	0.56±0.26	0.89±0.36	1.51±0.47
Texel	83	0.01±0.10	0.11±0.25	-0.31±0.35	-0.98±0.46
Southdown	44	-0.05±0.12	-0.48±0.33	-0.59±0.45	-1.24±0.59
Cotswold	43	0.14±0.13	0.39±0.35	0.51±0.47	0.87±0.62
Year		NS	NS	NS	NS
1976	259	0.01±0.05	0.20±0.14	0.45±0.19	0.08±0.25
1977	254	-0.01±0.05	-0.20±0.14	-0.45±0.19	-0.08±0.25
Ewe age (years)		***	***	***	***
Two	255	-0.27±0.04	-0.70±0.11	-0.96±0.15	-0.97±0.19
Three	258	0.27±0.04	0.70±0.11	0.96±0.15	0.97±0.19
Rearing type		***	***	***	***
Single	125	0.53±0.04	1.90±0.12	2.55±0.16	2.94±0.21
Twin	388	-0.53±0.04	-1.90±0.12	-2.55±0.16	-2.94±0.21
Sex		***	***	***	***
Female	249	-0.17±0.05	-0.42±0.12	-0.54±0.17	-0.70±0.23
Wether	264	0.17±0.05	0.42±0.12	0.54±0.17	0.70±0.23

7.1.2 Liveweight growth and carcass composition relative to age

7.1.2.1 Introduction

The results presented in this section were taken from two analyses of the data. In the first analysis a statistical model in which dams were nested within sires was fitted separately for each year's data. Slaughter group (11 classes) was fitted within dams and the results are presented in Section 7.1.2.2. In the second analysis dams were nested within sires within breed of sire and year. Slaughter group (11 classes) was fitted within dams and terms for the interactions of the modified slaughter group (4 classes, see Section 3.3.5) with year, breed of sire, breed of dam and rearing type were included. Fixed effects for all factors except slaughter group were taken from this analysis and reported in Sections 7.1.2.3 and 7.1.2.4.

7.1.2.2 Effect of slaughter group

The least squares means and fitted values for liveweight, side and dissectible tissue weights for each slaughter group within years are given in Tables 7.2 and 7.3. This information is also shown graphically in Figures 7.1 and 7.2. Low growth rates in 1976 were due to a severe drought. A feature of these growth curves is the loss of soft tissue weights between slaughter groups 8 and 10 and the subsequent rapid weight increase to slaughter group 11. Changes in live and side tissue weights over this period are summarised in Table 7.4. Dissected bone weight showed a relatively steady increase with age, although there were small non-significant fluctuations.

The pattern of weight change over this period differed between years. However, in both years of the experiment the loss

Table 7.2 Mean values (kg) for liveweight, side weight and dissectible tissue weights for eleven slaughter groups

1976-1977

	Live weight	Side weight	Lean	Total fat	Bone	Subcutaneous fat	Inter-muscular fat	KKCF
Mean	40.0	8.7	4.9	2.1	1.43	0.88	0.92	0.24
Slaughter group								
1	31.6	6.8	4.0	1.4	1.15	0.59	0.67	0.13
2	34.0	7.1	4.1	1.6	1.31	0.71	0.79	0.15
3	36.1	7.8	4.3	1.9	1.32	0.80	0.87	0.22
4	36.2	7.0	3.9	1.6	1.33	0.66	0.74	0.22
5	35.7	7.1	4.0	1.6	1.30	0.59	0.71	0.24
6	36.9	7.9	4.5	1.9	1.28	0.78	0.89	0.26
7	41.7	9.7	5.5	2.6	1.46	1.15	1.11	0.32
8	41.4	10.1	5.7	2.9	1.48	1.36	1.14	0.33
9	46.3	10.7	6.3	2.5	1.70	1.13	1.09	0.26
10	42.2	8.5	5.2	1.4	1.54	0.53	0.67	0.18
11	67.3	15.9	8.6	5.0	2.02	2.54	2.04	0.51

Table 7.3 Mean values (kg) for liveweight, side weight and dissectible tissue weights for eleven slaughter groups 1977-1978

	Live weight	Side weight	Lean	Total fat	Bone	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	44.4	9.7	5.32	2.74	1.44	1.27	1.12	0.33
Slaughter group								
1	33.3	7.0	4.01	1.66	1.17	0.72	0.75	0.17
2	35.0	8.1	4.76	1.92	1.27	0.93	0.78	0.22
3	39.2	8.1	4.53	2.03	1.23	0.93	0.86	0.22
4	41.6	8.7	4.58	2.74	1.27	1.32	1.14	0.30
5	45.2	10.4	5.27	3.41	1.51	1.61	1.34	0.46
6	45.7	10.2	5.42	3.34	1.37	1.60	1.32	0.40
7	50.4	11.6	6.26	3.60	1.56	1.77	1.40	0.41
8	53.2	12.4	6.51	3.96	1.67	1.99	1.48	0.49
9	52.5	11.6	6.16	3.39	1.69	1.44	1.42	0.49
10	45.1	9.8	5.46	2.37	1.62	0.97	1.07	0.28
11	52.9	10.9	6.22	2.80	1.66	1.29	1.14	0.35

Figure 7.1 Liveweight and side tissue weights relative to age (1976/77)

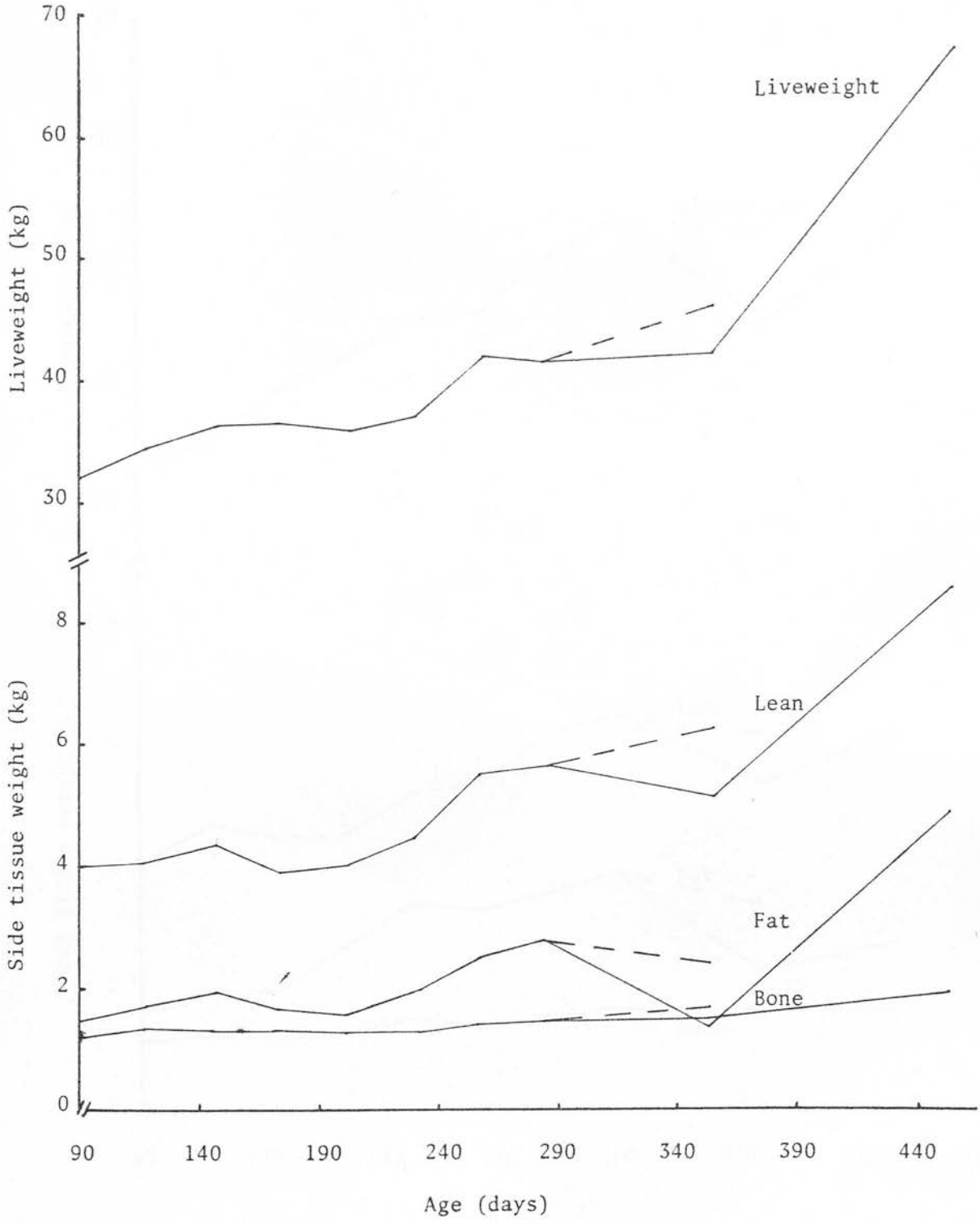


Figure 7.2 Live weight and side tissue weights relative to age (1977/78)

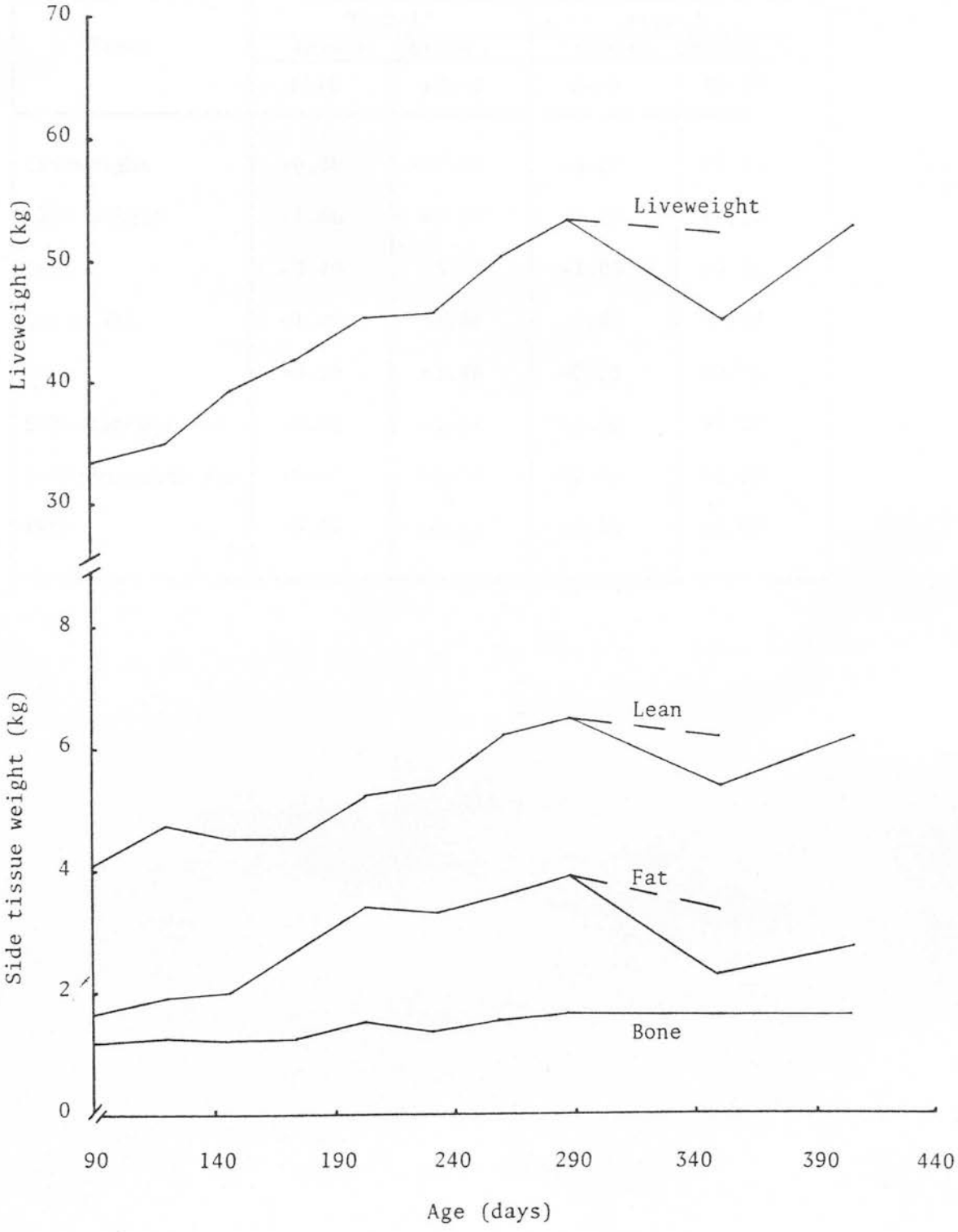


Table 7.4 Live and tissue weight (kg) changes between slaughter groups 8, 10 and 11 in two years

Trait	Year 1		Year 2	
	Growth period		Growth period	
	8-10	10-11	8-10	10-11
Liveweight	+0.80	+25.05	-8.07	+7.79
Side weight	-1.66	+7.39	-2.58	+1.14
Lean	-0.49	+3.43	-1.05	+0.76
Total fat	-1.41	+3.58	-1.59	+0.43
Bone	+0.06	+0.48	-0.05	+0.04
Subcutaneous fat	-0.83	+2.01	-1.02	+0.32
Intermuscular fat	-0.47	+1.37	-0.41	+0.07
KKCF	-0.15	+0.33	-0.21	+0.07

of total fat weight tended to be greater than the loss of lean tissue. This result is most apparent when weight loss is expressed as a proportion of weight at slaughter group 8 with losses of 8.5% and 16.1% for lean and 49.7% and 40% for fat in 1976 and 1977 respectively. Within the total fat, weight loss from the subcutaneous fat depot tended to be higher than losses from the intermuscular or KKCF depots. This result was found in both years of the experiment. The relative importance of the intermuscular and KKCF depots as sources of weight loss differed between years.

In 1976 the proportion of lean and fat in the weight gain between slaughter groups 10 and 11 was similar. In 1977 when a shorter recovery period was allowed and when previous liveweight changes were greater, lean tended to represent a higher proportion of the weight gain than fat. In both years of the experiment the weight gains of subcutaneous fat tended to be higher than for intermuscular fat or KKCF. As with weight loss, the relative importance of the intermuscular fat and KKCF depots was not clear.

Supplementary feeding over winter increased the live and tissue weights of animals in slaughter group 9 relative to their store fed contemporaries of slaughter group 10. The supplementary food did not necessarily maintain or increase the weights of fat and lean recorded for slaughter group 9 relative to slaughter group 8 animals.

7.1.2.3 Environmental factors and interactions

The interactions of year × sex, sire breed × sex, dam breed × sex, ewe age × sex, rearing-type × sex, sex × slaughter group, year × ewe age, slaugher group × ewe age, sire breed × ewe age,

rearing-type × ewe age, rearing-type × year, rearing-type × sire breed, rearing-type × dam breed and sire breed × year were not significant ($P > 0.05$). The interaction of year × slaughter group was significant ($P < 0.05$) for all traits.

The effects of ewe age and rearing-type (Table 7.5) were significant for all traits ($P < 0.001$). Deviations from the overall mean were greater for rearing-type than for ewe age effects. The difference between singles and twins expressed as a percentage of the least squares mean was greater for total fat than for lean and bone weights. Within fat depots the percentage difference tended to be higher for subcutaneous and KKCF depots than for intermuscular fat.

Wether lambs had significantly greater liveweight, side, lean and bone weights than females ($P < 0.05$). Although fat weights were consistently higher in the female than in the wether, this difference approached significance only for the subcutaneous fat depot ($P < 0.10$).

7.1.2.4 Breed of sire

The effect of breed of sire was significant for all traits examined except side weight. The Oxford and Suffolk crosses were heaviest at this age and the Southdown crosses were lightest. The Oldenburg, Oxford, Suffolk and Texel yielded a significantly greater weight of lean than the other breeds with the Texel tending to produce the most lean within this group. The Southdown produced more fat and less bone than any other breed ($P < 0.05$).

Table 7.5 Mean values (kg) for liveweight, side weight and dissectible tissue weights adjusted to a constant age[#]

	Number	Live weight	Side weight	Lean	Total fat	Bone	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	513	41.88	9.16	5.10	2.36	1.43	1.05	1.01	0.28
Year		*	NS	NS	NS	NS	NS	NS	NS
1976	259	40.92	9.02	5.05	2.26	1.44	0.99	0.96	0.27
1977	254	42.86	9.30	5.15	2.47	1.42	1.11	1.04	0.29
Ewe age (years)		***	***	***	***	***	*	***	***
Two	255	40.84	8.84	4.95	2.22	1.40	0.99	0.95	0.26
Three	258	42.94	9.49	5.26	2.52	1.46	1.11	1.08	0.30
Rearing type		***	***	***	***	***	***	***	***
Single	125	44.37	9.99	5.39	2.81	1.51	1.27	1.18	0.34
Twin	388	39.53	8.40	4.83	1.99	1.35	0.86	0.87	0.23

[#] 35 weeks

Table 7.5 continued. Comparison at a constant age[#]

	Number	Live weight	Side weight	Lean	Total fat	Bone	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	513	41.88	9.16	5.10	2.36	1.43	1.05	1.01	0.28
Sex		*	*	**	NS	***	NS	NS	NS
Female	249	40.89	8.94	4.95	2.41	1.37	1.12	1.01	0.28
Wether	264	42.89	9.38	5.25	2.32	1.49	0.97	1.01	0.28
Sire breed		*	NS	**	**	***	*	**	**
Dorset Down	88	41.75^{a}	9.07	4.94^{a}	2.51^{a}	1.38^{a}	1.12^{ab}	1.04^{a}	0.31^{ab}
Ile de France	43	41.00^{a}	8.81	4.86^{a}	2.35^{ab}	1.36^{a}	1.01^{abcd}	1.04^{ab}	0.28^{acd}
Oldenburg	43	41.00^{a}	8.94	5.24^{b}	1.93^{c}	1.47^{b}	0.83^{d}	0.85^{c}	0.27^{e}
Oxford	85	44.69^{b}	9.59	5.33^{b}	2.46^{a}	1.57^{c}	1.08^{abc}	1.06^{a}	0.29^{ac}
Suffolk	84	43.99^{b}	9.76	5.33^{b}	2.67^{ad}	1.53^{bc}	1.20^{ae}	1.13^{a}	0.32^{ab}
Texel	83	41.11^{a}	9.30	5.48^{b}	2.12^{bc}	1.41^{a}	0.92^{bcd}	0.93^{bc}	0.24^{de}
Southdown	44	40.44^{a}	9.30	4.85^{a}	2.97^{d}	1.26^{d}	1.39^{e}	1.18^{a}	0.37^{b}
Cotswold	43	41.26^{a}	8.58	4.82^{a}	2.08^{c}	1.47^{b}	0.92^{cd}	0.90^{c}	0.25^{cde}

35 weeks

7.1.3 The allometric relationship between side weight, dissectible tissue weights and liveweight

7.1.3.1 Allometric regression coefficients

The allometric regression coefficients for side weight and its dissected tissues, relative to liveweight, are presented in Table 7.6. The pooled coefficient for side weight of 1.16 ± 0.04 was significantly greater than one. The pooled coefficient for lean weight was not significantly different from one whilst the value for bone weight was significantly lower than unity. All values of the allometric coefficients for total fat and individual fat depots were significantly greater than one, with the subcutaneous fat depot increasing relative to liveweight at a significantly greater rate than the intermuscular fat or KKCF depots. The standard errors attached to these estimates were lowest for side, lean and bone weights and the multiple correlation coefficients (R^2) were highest for these traits.

The effects of fitting individual regression slopes for years, sire breeds, dam breeds, ewe ages and sexes were tested. The regression coefficients for the relationship between $\log_{10}$ lean weight and $\log_{10}$ liveweight differed significantly between years ($P < 0.05$) but other differences between slopes proved non-significant at the 5% level. Estimates of the individual regression slopes are given in Table 7.7. Differences between regression slopes for different years, ewe ages and sexes were small but the apparent differences between slopes for different breeds were larger and this was particularly true for the fat depots. However the standard errors attached to the individual breed regression estimates were large.

Table 7.6 Pooled allometric coefficients (b) for the growth of carcass tissues relative to liveweight and multiple correlation coefficients (R^2)

Trait	b ± s.e.	R^2
Side	1.16 ± 0.04	0.89
Lean	1.06 ± 0.04	0.85
Bone	0.73 ± 0.03	0.79
Total fat (inc. KKCF)	1.69 ± 0.10	0.68
Subcutaneous fat	2.01 ± 0.16	0.54
Intermuscular fat	1.49 ± 0.09	0.68
KKCF	1.43 ± 0.14	0.51

Table 7.7 Allometric coefficients for years, sire and dam breeds, ewe age and sex for the growth of carcass tissues relative to liveweight

	Side weight	Lean	Sub-cutaneous fat	Inter-muscular fat	Total fat exc. KKCF	Total fat	KKCF	Bone
Year								
1976	1.18±0.04	1.11±0.04	2.10±0.19	1.49±0.10	1.77±0.12	1.70±0.12	1.49±0.16	0.72±0.04
1977	1.10±0.07	0.92±0.07	1.76±0.37	1.48±0.17	1.62±0.20	1.68±0.19	2.10±0.27	0.75±0.07
Sire breed								
Dorset Down	1.11±0.08	0.98±0.08	1.85±0.35	1.33±0.19	1.59±0.23	1.64±0.22	1.92±0.30	0.77±0.07
Ile de France	1.10±0.10	0.85±0.11	2.20±0.49	1.80±0.26	2.01±0.32	2.07±0.30	2.60±0.41	0.46±0.10
Oldenburg	1.33±0.12	1.28±0.13	2.47±0.58	1.69±0.31	1.91±0.38	1.76±0.36	1.06±0.49	0.96±0.12
Oxford	1.22±0.09	1.17±0.10	2.16±0.43	1.38±0.23	1.76±0.28	1.70±0.27	1.34±0.36	0.68±0.09
Suffolk	1.16±0.08	1.15±0.08	1.67±0.37	1.24±0.20	1.44±0.24	1.41±0.23	1.31±0.31	0.80±0.07
Texel	1.15±0.09	1.05±0.10	2.22±0.43	1.77±0.23	1.98±0.28	1.80±0.27	1.27±0.36	0.73±0.09
Southdown	1.15±0.14	0.92±0.15	1.85±0.64	1.53±0.35	1.70±0.43	1.75±0.40	2.21±0.54	0.71±0.13
Cotswold	1.08±0.16	0.96±0.17	1.87±0.74	1.45±0.40	1.64±0.49	1.66±0.46	1.98±0.63	0.71±0.15

Table 7.7 continued. Allometric coefficients for years, sire and dam breeds, ewe age and sex for the growth of carcass tissues relative to liveweight

	Side weight	Lean	Sub-cutaneous fat	Inter-muscular fat	Total fat exc. KKCF	Total fat	KKCF	Bone
Dam breed								
Tex-Old#	1.16±0.12	0.96±0.13	1.96±0.56	1.73±0.30	1.81±0.37	1.84±0.35	2.17±0.49	0.71±0.12
Dam Line	1.18±0.05	1.07±0.05	2.09±0.23	1.58±0.12	1.82±0.15	1.75±0.14	1.52±0.20	0.72±0.05
Greyface	1.16±0.06	1.10±0.06	1.94±0.26	1.33±0.14	1.61±0.17	1.60±0.16	1.63±0.22	0.78±0.05
Blackface	0.88±0.17	0.71±0.19	1.76±0.81	1.44±0.44	1.59±0.54	1.70±0.51	2.49±0.70	0.45±0.17
Ewe age (years)								
Two	1.15±0.05	1.04±0.05	2.03±0.21	1.56±0.12	1.78±0.14	1.74±0.13	1.72±0.19	0.70±0.05
Three	1.17±0.05	1.08±0.06	1.99±0.24	1.40±0.13	1.66±0.16	1.64±0.15	1.56±0.21	0.76±0.05
Sex								
Female	1.15±0.05	1.01±0.05	1.98±0.22	1.57±0.12	1.76±0.15	1.73±0.14	1.77±0.19	0.75±0.05
Wether	1.17±0.05	1.09±0.05	2.03±0.21	1.41±0.12	1.70±0.14	1.66±0.13	1.54±0.19	0.71±0.04

Group of Texel and Oldenburg cross ewes.

Curvilinearity in the log-log relationship was tested by fitting a term for $(\log_{10}$ liveweight$)^2$ but without a significant reduction in the residual variance.

7.1.3.2 Environmental effects

Mean values (i.e. antilog of $\log_{10} \hat{y}$ at $\log_{10} \bar{x}$) for environmental factors compared at a constant liveweight of 41.6 kg are shown in Table 7.8. After correction for differences in liveweight the effects of year were non-significant at the 5% level for all traits except bone weight which was slightly higher in 1976 than 1977 ($P < 0.001$). Differences in side weight and composition outlined for comparisons made at constant age (Section 7.1.2.3) were removed or reduced by correction for differences in liveweight. Lambs reared by two year-old ewes produced lower weights of KKCF and intermuscular fat than lambs reared by three year-old ewes ($P < 0.05$). Differences between lambs of different rearing type compared at a constant age were not totally explained by variation in liveweight. When compared at the same liveweight females produced less bone and more subcutaneous fat than wethers.

None of the interaction effects tested proved important.

7.1.3.3 Breed of sire

The sire breed effect was highly significant for all traits examined (Table 7.8). The Southdown and Texel crossbred lambs produced the highest side weights (KO%) but differed considerably from one another in terms of composition. The Southdown produced the lowest weight of bone and the highest weights of total fat and individual fat depots whilst yielding an intermediate weight of

Table 7.8 Mean values (kg) for side and dissectible tissue weights regressed to a constant liveweight[#]

	No.	Side weight	Lean	Total fat	Bone	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	513	9.06	5.05	2.34	1.42	1.04	1.00	0.27
Year		NS	NS	NS	***	NS	NS	NS
1976	259	9.13	5.10	2.33	1.46	1.02	1.01	0.27
1977	254	8.99	4.99	2.35	1.38	1.06	0.99	0.27
Ewe age (years)		NS	NS	NS	NS	NS	*	*
Two	255	9.02	5.05	2.28	1.41	1.02	0.97	0.26
Three	258	9.11	5.05	2.41	1.42	1.06	1.03	0.29
Rearing type		***	NS	***	*	***	***	*
Single	125	9.27	5.03	2.56	1.43	1.16	1.08	0.30
Twin	388	8.86	5.06	2.14	1.40	0.93	0.93	0.25
Sex		NS	NS	NS	***	*	NS	NS
Female	249	9.03	5.03	2.40	1.38	1.12	1.01	0.28
Wether	264	9.09	5.07	2.28	1.46	0.97	0.99	0.27

41.59 kg.

Table 7.8 continued Comparison at a constant liveweight[#]

	No.	Side weight	Lean	Total fat	Bone	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	513	9.06	5.05	2.34	1.42	1.04	1.00	0.27
Sire breed		**	***	***	***	**	***	***
Dorset Down	88	9.12^{ab}	4.90^{a}	2.60^{a}	1.37^{a}	1.16^{a}	1.09^{a}	0.33^{a}
Ile de France	43	8.87^{ac}	5.03^{a}	2.16^{b}	1.41^{ab}	0.93^{bc}	0.96^{b}	0.25^{bc}
Oldenburg	43	8.91^{ac}	5.31^{b}	1.88^{d}	1.45^{bcd}	0.82^{c}	0.83^{c}	0.19^{d}
Oxford	85	8.86^{ac}	4.94^{a}	2.23^{b}	1.49^{d}	0.99^{b}	0.96^{b}	0.25^{b}
Suffolk	84	9.12^{ab}	4.97^{a}	2.46^{ac}	1.47^{cd}	1.09^{ab}	1.06^{a}	0.29^{ac}
Texel	83	9.38^{bd}	5.45^{b}	2.25^{bc}	1.43^{bc}	0.99^{b}	0.97^{b}	0.27^{bc}
Southdown	44	9.60^{d}	4.97^{a}	3.15^{e}	1.29^{e}	1.48^{d}	1.24^{d}	0.40^{e}
Cotswold	43	8.68^{c}	4.85^{a}	2.20^{b}	1.46^{bcd}	0.97^{bc}	0.94^{b}	0.26^{bc}

41.59 kg.

dissectible lean tissue. The Texel cross produced a high lean weight and weight of fat and bone which did not differ significantly from the overall mean for these traits. Although the Oldenburg cross produced a significantly lighter side than the Texel ($P < 0.05$) the weight of lean produced was similar for both crosses. The weight of total fat and individual fat depot weights was significantly lower in the Oldenburg than in other crosses ($P < 0.05$). The side and tissue weights produced by the Ile de France, Oxford and Cotswold were not significantly different ($P > 0.05$).

The Dorset Down and Suffolk crosses tended to yield heavier sides than the Ile de France although this effect was not significant at the 5% level. Total fat weight was significantly greater ($P < 0.05$) in the Dorset Down and Suffolk than in the Ile de France and bone weight was also significantly higher ($P < 0.05$) in the Suffolk cross.

7.1.4 The allometric relationship between dissectible tissue weight and side weight

7.1.4.1 Allometric regression coefficients

The pooled regression coefficients for lean and bone were significantly lower than 1.0 whilst those for total fat and individual fat depots were significantly greater than 1.0 (Table 7.9). The highest allometric coefficient was found for the subcutaneous fat depot and the regression coefficient for the KKCF depot tended towards a higher value than that for intermuscular fat.

Differences between individual regression slopes for years, sire and dam breeds, ewe ages and sexes were tested (Table 7.10). Individual regressions within years proved significant for lean and KKCF while individual regressions within sire breed significantly

Table 7.9 Pooled allometric coefficients (b) and multiple correlation coefficients (R^2) for the growth of carcass tissues relative to side weight

Trait	b ± s.e.	R^2
Lean weight	0.91 ± 0.02	0.95
Bone	0.59 ± 0.03	0.77
Total fat	1.53 ± 0.06	0.83
Subcutaneous fat	1.87 ± 0.10	0.70
Intermuscular fat	1.31 ± 0.06	0.79
KKCF	1.45 ± 0.10	0.59

Table 7.10 Allometric coefficients for years, sire and dam breeds, ewe age and sex for the growth of carcass tissues relative to side weight

	Lean	Bone	Total fat	Sub-cutaneous fat	Inter-muscular fat	KKCF
Year						
1976	0.93±0.02	0.56±0.03	1.51±0.07	1.92±0.12	1.30±0.07	1.31±0.12
1977	0.83±0.04	0.66±0.06	1.57±0.12	1.71±0.21	1.34±0.12	1.93±0.21
Sire breed						
Dorset Down	0.89±0.04	0.68±0.06	1.48±0.13	1.73±0.24	1.16±0.13	1.67±0.22
Ile de France	0.81±0.06	0.36±0.09	1.90±0.19	2.04±0.34	1.65±0.18	2.28±0.32
Oldenburg	0.95±0.06	0.62±0.09	1.51±0.18	2.29±0.33	1.38±0.17	0.80±0.31
Oxford	0.95±0.05	0.53±0.07	1.45±0.15	1.84±0.27	1.15±0.14	1.26±0.25
Suffolk	0.97±0.04	0.61±0.07	1.34±0.14	1.58±0.24	1.15±0.13	1.29±0.23
Texel	0.91±0.05	0.61±0.08	1.63±0.16	2.09±0.28	1.54±0.15	1.22±0.27
Southdown	0.75±0.07	0.60±0.12	1.62±0.24	1.73±0.43	1.43±0.23	1.94±0.41
Cotswold	0.91±0.09	0.63±0.14	1.52±0.30	1.77±0.53	1.28±0.28	1.74±0.50

Table 7.10 continued. Allometric coefficients for years, sire and dam breeds, ewe age and sex for the growth of carcass tissues relative to side weight

	Lean	Bone	Total fat	Sub-cutaneous fat	Inter-muscular fat	KKCF
Dam breed						
Tex-Old	0.83±0.06	0,61±0,10	1.61±0,21	1,79±0.37	1,42±0,20	1.89±0.35
Dam Line	0.90±0.03	0.57±0.04	1.54±0.08	1.88±0.15	1.36±0.08	1.38±0.15
Greyface	0.94±0.03	0.61±0.05	1.46±0.09	1.84±0.17	1.19±0.09	1.39±0.16
Blackface	0.70±0.12	0.42±0.18	2.16±0.38	2.36±0.67	1.84±0.36	2.82±0.65
Ewe age (years)						
Two	0.90±0.03	0.57±0.04	1.59±0.08	1.90±0.14	1.39±0.08	1.51±0.14
Three	0.91±0.03	0.60±0.04	1.46±0.09	1.84±0.15	1.21±0,08	1.39±0.15
Sex						
Female	0.88±0.03	0.60±0.04	1.58±0.08	1.84±0.15	1.40±0.08	1.58±0.15
Wether	0.93±0.02	0.57±0.04	1.49±0.08	1.89±0.14	1.23±0.07	1.36±0.13

reduced residual variation in the analysis of KKCF. As so few of these individual regressions tested proved significant relative to the number tested and because the traits examined were not independent it was decided to ignore this result and continue the analysis using pooled regressions.

The term $(\log x)^2$ did not significantly reduce the residual variation of any of the traits examined.

7.1.4.2 Environmental effects

The effects of year, ewe age, rearing type and sex upon carcass composition at constant side weight were similar to the effects recorded at constant liveweight (Table 7.11).

None of the interactions tested were important.

7.1.4.3 Sire breed

Least squares means and fitted constants for sire breed comparisons at a constant side weight of 8.95 kg are given in Table 7.11. The sire breed effect was highly significant ($P < 0.001$) for all traits examined. Some small changes in ranking of the breeds was evident when analyses at constant live and constant side weight were compared. The Southdown cross and Dorset Down crosses contained the lowest proportion of lean in the side whilst Oldenburg and Texel crosses contained the highest proportion. The disadvantage of the low side weight of the Oldenburg cross at constant live weight (Section 7.1.3.3) was removed by comparison at constant side weight and this cross tended to yield a higher weight of lean than the Texel. Breeds ranked for weight of total fat at constant side weight in reverse order to their ranking for lean weight produced.

Table 7.11 Mean values (kg) for dissectible tissue weights for year, rearing type and ewe age when adjusted to constant side weight[#]

	Number	Lean	Bone	Total fat	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	513	5.00	1.41	2.29	1.01	0.98	0.27
Year		NS	*	NS	NS	NS	NS
1976	259	5.01	1.44	2.27	0.99	0.99	0.27
1977	254	4.98	1.38	2.31	1.04	0.98	0.27
Ewe age (years)		NS	NS	NS	NS	*	*
Two	255	5.02	1.41	2.25	1.01	0.96	0.26
Three	258	4.97	1.41	2.34	1.02	1.01	0.28
Rearing type		***	NS	***	**	***	*
Single	125	4.88	1.41	2.40	1.02	1.03	0.28
Twin	388	5.11	1.41	2.19	1.01	0.94	0.26

8.95 kg.

Table 7.11 continued. Comparison at a constant side weight[#]

	Number	Lean	Bone	Total fat	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	513	5.00	1.41	2.29	1.02	0.98	0.27
Sex		NS	***	*	**	NS	NS
Female	249	4.99	1.37	2.37	1.10	1.00	0.28
Wether	264	5.00	1.45	2.22	0.94	0.97	0.26
Sire breed		***	***	***	**	***	***
Dorset Down	88	4.82^{d}	1.36^{c}	2.53^{b}	1.12^{b}	1.07^{b}	0.32^{a}
Ile de France	43	5.07^{bc}	1.41^{bc}	2.20^{cd}	0.95^{cd}	0.97^{d}	0.26^{bc}
Oldenburg	43	5.35^{a}	1.47^{ab}	1.87^{e}	0.82^{e}	0.84^{f}	0.19^{d}
Oxford	85	4.99^{c}	1.50^{a}	2.25^{cd}	1.00^{cd}	0.97^{d}	0.25^{c}
Suffolk	84	4.90^{cd}	1.46^{ab}	2.37^{bc}	1.04^{bc}	1.03^{bc}	0.28^{b}
Texel	83	5.23^{ab}	1.38^{c}	2.10^{d}	0.91^{de}	0.91^{e}	0.25^{c}
Southdown	44	4.66^{e}	1.23^{d}	2.84^{a}	1.32^{a}	1.14^{a}	0.35^{a}
Cotswold	43	4.98^{cd}	1.48^{ab}	2.30^{c}	1.03^{bcd}	0.98^{cd}	0.28^{bc}

8.95 kg.

7.1.5 The allometric relationship between fat depot weight and dissectible lean weight

7.1.5.1 Allometric regression coefficients

The allometric coefficients for the relationships between $\log_{10}$ total fat and fat depot weights relative to $\log_{10}$ lean weight are shown in Table 7.12. All values of the pooled regression coefficients were significantly greater than unity. The regression coefficients for the intermuscular and KKCF depots were not significantly different but the subcutaneous fat depot increased more rapidly relative to lean weight. Curvilinearity in the log-log relationships did not approach significance for any relationship examined. Differences between individual regression slopes within year of birth were significant only for the KKCF depot ($P < 0.05$), the rate of KKCF deposition being greatest in 1977 (Table 7.13).

Individual slopes for sire and dam breeds did not significantly reduce the residual variation when compared with a model fitting the pooled regression slopes. Although wide variations in the within breed regression coefficients were observed the standard errors attached were high.

Ewe age did not significantly affect the rate of fat deposition relative to lean weight although estimates of the regression coefficient were consistently higher for the younger ewe.

Although the regression slopes were consistently higher for females than for wethers, differences between slopes reached significance only for the intermuscular fat depot ($P < 0.05$).

Table 7.12 Pooled allometric coefficients (b) and multiple correlation coefficients (R^2) for the deposition of fat relative to lean weight

Trait	b ± s.e.	R^2
Total fat	1.45 ± 0.09	0.65
Subcutaneous fat	1.78 ± 0.14	0.55
Intermuscular fat	1.24 ± 0.08	0.63
KKCF	1.31 ± 0.13	0.42

Table 7.13 Allometric coefficients for the relationships between $\log_{10}$ fat depot weight and $\log_{10}$ lean weight

	Sub-cutaneous fat	Inter-muscular fat	KKCF	Total fat
Pooled regression	1.78±0.14	1.24±0.08	1.31±0.13	1.45±0.09
Year				
1976	1.81±0.15	1.23±0.09	1.18±0.15	1.43±0.10
1977	1.64±0.30	1.30±0.18	1.84±0.29	1.51±0.20
Sire breed				
Dorset Down	1.82±0.32	1.22±0.19	1.70±0.30	1.54±0.21
Ile de France	2.11±0.49	1.72±0.29	2.23±0.45	1.96±0.32
Oldenburg	2.01±0.42	1.31±0.25	0.71±0.39	1.42±0.27
Oxford	1.81±0.34	1.10±0.20	1.22±0.32	1.41±0.22
Suffolk	1.34±0.30	0.96±0.17	0.99±0.27	1.11±0.19
Texel	2.00±0.37	1.45±0.22	1.10±0.34	1.55±0.24
Southdown	2.01±0.67	1.63±0.40	2.36±0.63	1.88±0.44
Cotswold	1.40±0.68	1.06±0.40	1.25±0.63	1.21±0.44
Dam breed				
Tex-old	1.77±0.52	1.44±0.31	1.84±0.49	1.59±0.34
Dam Line	1.76±0.20	1.26±0.12	1.17±0.19	1.41±0.13
Greyface	1.77±0.22	1.16±0.13	1.31±0.20	1.42±0.14
Blackface	2.49±1.07	1.97±0.64	3.54±1.01	2.36±0.71
Ewe age (years)				
Two	1.85±0.19	1.35±0.11	1.42±0.18	1.54±0.12
Three	1.69±0.20	1.12±0.12	1.19±0.19	1.34±0.13
Sex				
Female	1.90±0.20	1.43±0.12	1.49±0.19	1.59±0.13
Wether	1.68±0.17	1.10±0.10	1.18±0.17	1.34±0.11

7.1.5.2 Environmental effects

Least squares means for comparisons at a constant lean weight of 5.04 kg are given in Table 7.14. The year effect was non-significant for all traits examined. Lambs reared by three year-old ewes produced more KKCF and intermuscular fat ($P < 0.05$) than lambs reared by two year-old ewes and similar, although non-significant trends were observed for subcutaneous and total fat weight. Single lambs produced a greater weight of fat than twin lambs in all depots. Although female lambs tended to have greater weights of all depot fats than wethers, the effect was significant only for the subcutaneous fat depot.

None of the interactions tested proved important.

7.1.5.3 Sire breed

The sire breed effect was highly significant ($P < 0.001$) for all traits (Table 7.14). This analysis also demonstrated the high level of fat deposition in the Southdown and the considerably lower fat deposition of the Oldenburg and Texel crosses. The Dorset Down cross contained significantly ($P < 0.05$) more fat than the overall breeds mean. The Cotswold and Oxford deposited similar weights of fat in all depots and the Suffolk cross was intermediate between these two breeds and the Dorset Down.

The ratio of subcutaneous : intermuscular fat as estimated from the breed means (Table 7.14) was highest in the Southdown (1.20), lowest in the Oldenburg (0.96), Ile de France (0.97), Texel (0.99) and intermediate for the Oxford (1.04), Suffolk (1.04), Cotswold (1.05) and Dorset Down (1.07).

Table 7.14 Mean values for fat depot weights (kg) at a constant weight of lean[#]

	Number	Total fat	Sub-cutaneous fat	Inter-muscular fat	KKCF
Mean	513	2.37	1.04	1.00	0.27
Ewe age (years)		NS	NS	*	*
Two	255	2.27	1.02	0.97	0.26
Three	258	2.41	1.06	1.04	0.29
Rearing type		***	***	***	***
Single	125	2.59	1.17	1.10	0.30
Twin	388	2.12	0.92	0.91	0.25
Year		NS	NS	NS	NS
1976	259	2.26	0.99	0.99	0.27
1977	254	2.42	1.09	1.02	0.28
Sex		NS	*	NS	NS
Female	249	2.41	1.12	1.01	0.28
Wether	264	2.28	0.97	0.99	0.27
Sire breed		***	**	***	***
Dorset Down	88	2.43^{a}	1.21^{a}	1.13^{a}	0.34^{a}
Ile de France	43	2.16^{bc}	0.93^{bd}	0.96^{bd}	0.25^{b}
Oldenburg	43	1.78^{d}	0.77^{d}	0.80^{e}	0.18^{d}
Oxford	85	2.32^{ce}	1.04^{bc}	1.00^{bc}	0.26^{b}
Suffolk	84	2.53^{ae}	1.12^{ac}	1.08^{ac}	0.30^{ac}
Texel	83	2.01^{bd}	0.87^{bd}	0.88^{d}	0.24^{b}
Southdown	44	3.18^{f}	1.50^{e}	1.25^{f}	0.40^{e}
Cotswold	43	2.31^{ce}	1.03^{b}	0.98^{bc}	0.28^{bc}

[#] 5.04 kg.

7.1.6 The allometric relationship between lean and bone

7.1.6.1 Allometric regression coefficients

The quadratic term proved significant ($P < 0.01$) for this relationship, the coefficients being $b_1 = -3.81$ and $b_2 = 1.16$, with a multiple correlation coefficient (R^2) of 0.77. Allometric coefficients taken from analyses which did not include the quadratic term are given in Appendix Table A.7.1. Curvilinear regressions were not fitted within individual breeds or environmental factors.

7.1.6.2 Fixed effects

Mean values of lean weight at constant bone weight are presented in Table 7.15.

Lean to bone ratio was significantly higher in 1977 than 1976 ($P < 0.01$) but was not affected by ewe age. Twins produced significantly more lean than singles at a constant bone weight ($P < 0.05$) while females tended to have a higher lean to bone ratio than wethers ($P < 0.06$).

Lean to bone ratio was highest in the Southdown and Texel and lowest in the Cotswold, Oxford and Suffolk.

None of the interactions examined proved important.

7.1.7 Effects of rearing type upon the allometric relationships

Individual regression slopes for rearing type could not be fitted within dams and were not examined in the analyses described previously. Subsequently, individual regression slopes for rearing type were fitted within sires and the significance of differences between slopes was tested against the between dams mean square (Table 7.16). The rate of growth of side weight relative to liveweight approached, and the rates of total fat, intermuscular fat and KKCF deposition

Table 7.15 Mean values for lean weights (kg) adjusted to a constant weight of bone[#]

	Number	Lean
Mean	513	5.04
Year		**
1976	259	4.90
1977	254	5.18
Sire breed		
Dorset Down	88	5.05[a]
Ile de France	43	4.98[ab]
Oldenburg	43	5.10[a]
Oxford	85	4.73[b]
Suffolk	84	4.86[ab]
Texel	83	5.43[c]
Southdown	44	5.48[c]
Cotswold	43	4.72[b]
Ewe age (years)		NS
Two	255	5.05
Three	258	5.02
Rearing type		*
Single	125	4.97
Twin	388	5.11
Sex		NS
Female	249	5.13
Wether	264	4.94

[#] 1.41 kg.

Table 7.16 A summary of allometric coefficients (b) for single (1) and twin (2) rearing types

Independent variate / Trait		Live weight b ± se	Side weight b ± se	Lean weight b ± se
Side weight	(1)	1.06±0.05		
	(2)	1.15±0.02		
Lean weight	(1)	1.01±0.05	0.88±0.03	
	(2)	1.06±0.02	0.90±0.01	
Subcutaneous fat	(1)	1.45±0.21	1.64±0.15	1.29±0.21
	(2)	1.87±0.10	1.79±0.07	1.60±0.09
Intermuscular fat	(1)	1.22±0.12	1.26±0.09	0.99±0.13
	(2)	1.48±0.06	1.32±0.04	1.21±0.06
Total fat	(1)	1.35±0.15	1.49±0.09	1.16±0.15
	(2)	1.68±0.07	1.55±0.04	1.40±0.06
KKCF	(1)	1.39±0.20	1.63±0.15	1.21±0.20
	(2)	1.83±0.09	1.67±0.07	1.50±0.09
Bone	(1)	0.71±0.05	0.56±0.04	
	(2)	0.76±0.02	0.60±0.02	

relative to the liveweight reached significance at the five per cent level. Regression coefficients for all traits relative to side weight and lean weight did not differ significantly ($P > 0.05$) although there was a trend for the rate of fat deposition relative to both side and lean weights to be higher for twins than singles.

7.2 DISCUSSION

7.2.1 Method of analysis

The nested analysis of variance used with the serial slaughter data involved the estimation of regression coefficients (b) within dams. This approach has not been used in any previously published work and although it takes note of the genetic structure of the data and removes biases arising from differences between sires and dams, there are drawbacks. Since only dams with twin lambs contribute to the estimate of the regression, information from single lambs is lost at this level of the analysis. Some authors, e.g. Fourie *et al.* (1970) have shown significant differences for regression slopes fitted within breeds. Since small differences in regression slope will lead to different predictions of Y at values of the independent variable (X) which are distant from $\bar{X}$, it is pertinent to ask whether the statistical method used in this study has led to a different conclusion from that which would have been reached had individual regression slopes been tested at higher levels of the hierarchy. Estimates of the individual breed regression slopes of all traits against liveweight and of fat weights against lean weight, for each statistical model are shown in Appendix Tables A.6.1-11. Regression coefficients estimated within dams had higher standard errors and were more variable between sire breeds than when the estimates were derived from

higher levels of the hierarchy. However, the conclusion that regression slopes within individual sire breeds were not significantly different held at all levels of the analysis. The use of a common regression slope within environmental factors, rather than individual regression slopes, did not bias the estimates of sire breed means for dependent variates when compared at the mean value of the independent variable.

The significant effect of year on the estimates of the regression slopes of lean against live and side weights was not considered in the analyses (Sections 7.1.3.1 and 7.1.4.1). However, a comparable result was reported by Boccard and Dumont (1970) who found that for milk fed, male lambs between birth and 2.5 months of age an increase in growth rate from 75 g/day to 275 g/day significantly reduced the allometric coefficient of lean on empty body weight.

7.2.2 Patterns of tissue growth

The allometric coefficients for the growth of lean, fat and bone relative to live and side weights were in general fairly similar to those in the literature as summarised in Tables 2.1 to 2.4. The allometric coefficient of 1.06 ± 0.04 for the growth of lean tissue relative to liveweight would suggest that liveweight is a good predictor of lean weight. However, in practice varying gut-fill may affect the accuracy of prediction.

The finding that the rate of fat deposition in the subcutaneous depot relative to live, side and lean weights was greater than the rates of deposition in intermuscular and KKCF is in keeping with the results of Kirton *et al.* (1972), Fourie *et al.* (1970) and Murray and Slezacek (1976). Relative to side weight the rate of KKCF deposition

tended to be greater than the rate of intermuscular fat deposition ($P > 0.05$), as found by Fourie *et al.* (1970) and Murray and Slezacek (1976). However, Wood, Macfie, Pomeroy and Twinn (1979) present results which indicate that the rates of deposition of KKCF relative to carcass weight and to total fat weight may be similar to those of the subcutaneous fat depot.

Significant curvilinearity in the log-log relationships of carcass tissue weights with jointed side weight was reported by Seebeck (1966). This was not found in the present analysis. Evans and Kempster (1979) were able to demonstrate a significant ($P < 0.05$) quadratic effect for the relationship between lean weight and carcass weight in pigs.

There seems to be no published work in which a quadratic term was tested for the log-log relationship between lean and bone. Jackson (1967) considered that this relationship appeared to be linear for Blackface wethers slaughtered at birth, 5 months or 18 months of age. However, the differences in $\log_{10}$ bone weight between lambs slaughtered at 5 months or 18 months of age were perhaps too small to allow curvilinearity to be detected in this data. The results of the present analysis would suggest that the rate of lean growth relative to bone was increasing as the animal matured.

7.2.3 The effect of rearing type

The indications of this analysis are that single lambs contain more fat than twins when compared at a constant liveweight, side weight or lean weight. However the rates of fat deposition relative to these independent variates tend to be greater in twins

than in singles. The pattern of these results is similar to that reported by Wilson (1975) who found that the intercepts for weight of ether extract were higher whilst rates of deposition relative to side weight or protein weight were lower in single lambs than in twins. However Wilson (1975) was unable to demonstrate a significant effect of rearing type on intercept or rate of deposition of dissectible fatty tissue.

Wilson (1975) was also unable to demonstrate a significant effect of birth-rearing type on the intercepts or rates of dissectible lean tissue growth relative to side or bone weights. However single lambs did have a lower intercept and a higher rate of protein deposition relative to side weight than twins. The comparison of rearing type means at constant side or bone weights in this analysis are consistent with these results but rates of lean growth were consistently, although non-significantly, higher for twin lambs. It is possible that rearing type effects on dissectible lean tissue growth are complicated by differences in the pattern of intramuscular fat deposition.

7.2.4 The effect of ewe age

The effects of ewe age upon carcass composition and growth patterns were small. However the effects were in the same direction as those of rearing type with the more disadvantaged group (lambs reared by two year old ewes) tending to have less fat and non-significantly faster rates of fat deposition than lambs reared by three year old ewes.

7.2.5 The effect of sex

The literature (Section 2.2.4) would suggest that females yield more fat and less muscle and bone than wethers when compared at constant live or side weights. The results of the present analysis are in broad agreement with this conclusion although sex differences for lean yield did not reach significance. The results also indicate that the major difference in total fat yield arises in the subcutaneous fat depot, which is in agreement with the results of Seebeck (1966). The lack of significant differences between allometric coefficients for the two sexes would suggest that differences in gross carcass composition have developed before the weight range examined in this experiment. However females showed a consistent trend towards greater rates of fat deposition than wethers, particularly when fat deposition was studied relative to lean weight. This trend is consistent with previously published results (Section 2.2.4). In studies of bovine carcass fat deposition relative to carcass muscle weight Berg and Butterfield (1976) and Berg, Jones, Price, Fukuhara, Butterfield and Hardin (1979) conclude that differences in fatness between sexes are due to a combination of differences in the time of onset of rapid fattening and the rate of fattening. However, the allometric coefficients for steers and heifers did not differ significantly (Berg *et al.*, 1979).

Sex effects on the relationship between dissectible lean and bone are not clear. The sexes did not differ significantly for the weight of lean at constant bone weight. This result was not in keeping with the sex effects on weight of lean and bone at constant live and side weights which suggested that females have higher lean

to bone ratios than wethers. Wilson (1975) was unable to demonstrate a significant effect of sex on either the intercept or slope of the allometric relationship between lean and bone. Females, however, had significantly lower intercepts and slope than wethers for the relationship between protein and ash. There seems to be no other comparable evidence for either cattle or sheep.

7.2.6 The effect of breed

A number of published studies (Section 2.2.3) would suggest that rates of fat deposition tend to be greater in breeds of small mature size than in larger breeds (Fourie *et al.*, 1970; Wilson, 1975; Knapman, 1976). Conversely the rates of lean growth relative to carcass weight (Fourie *et al.*, 1970) or bone weight (Wilson, 1975) were higher in breeds of large mature size. In cattle Charles and Johnson (1976) indicate that the rate of fat deposition relative to carcass weight between 12 and 18 months of age was greater in the Hereford and Angus than in the Friesian or Charolais cross. Berg, Andersen and Liboriussen (1978) found a trend towards a low rate of lean growth relative to several size dimensions in the Hereford and a high rate in the Blonde d'Aquitaine. However Mukhoty and Berg (1971) found that rates of fat deposition relative to muscle plus bone weight were higher in Holstein and other dairy breeds than in the Hereford or Shorthorn.

The results of the current sheep experiment offer no support for this hypothesis. Individual regression slopes for sire breeds differed significantly only for the relationship between KKCF and side weight. There was little evidence to suggest that rates of fat deposition relative to any size dimension were greater in breeds of

small mature size but the rate of lean growth relative to side weight tended to be lower in the Southdown than in the other breeds. These results suggest that breed differences in tissue weights are constant over the range of liveweights studied in this experiment. However, such differences must have been caused by differential tissue growth between breeds at earlier stages of growth. Extension of the experiment to cover lighter slaughter weights may have allowed breed differences in allometric coefficients to be detected.

In general the breed comparison results of the serial slaughter trial were similar to those for lambs slaughtered at one of two fixed slaughter weights (Chapter 4). Liveweight adjusted to a constant age was highest in the Oxford and Suffolk, a result which is directly comparable to the lower age of slaughter estimated for these breeds at a constant slaughter weight of 39 kg (Section 4.2.3). The high lean yield of the Texel cross at a constant age again suggests that although liveweight growth rate of the Texel may be lower than those of the Oxford and Suffolk, the rates of lean tissue growth are similar in all three breeds.

Of the six sire breeds common to both the fixed slaughter weight and serial slaughter experiments, the performance of the Oldenburg differed most between the two experiments. The low killing-out percentage found in the first Trial was improved. Lean meat production also tended to be higher, with lean yield at a constant age approaching that of the Oxford and Suffolk and lean : fat ratio at constant lean weight tending to exceed that of the Texel. The disparity between the results of the two experiments must be treated with some caution. The Oldenburg breed in Great Britain is numerically small and due to its

comparatively recent introduction and subsequent grading-up programmes may be genetically heterogeneous. The number of sires represented in the two experiments was also small and on the basis of this criterion least emphasis can be given to the results of the serial slaughter experiment.

The ranking of the Southdown, Suffolk and Cotswold cross lambs was similar to that reported by Knapman (1976). The low side weight relative to liveweight for the Cotswold cross is in agreement with the results of Knapman (1976) who reported that the low killing-out percent of the Cotswold cross was almost entirely due to greater weights of wool, head, skin and feet. In this experiment the performance of the Cotswold cross at a constant age was below that of the Oxford cross. When comparisons were made relative to various weights, the carcass composition of the Oxford and Cotswold did not differ significantly. It therefore seems likely that the Cotswold has little more to offer than the Oxford as a sire of terminal meat lambs.

7.2.7 Optimum slaughter weights

Serial slaughter experiments allow the estimation of the mean liveweight for each breed at which an optimum carcass composition is achieved. The carcass most desired by the consumer would contain maximum lean, minimum bone and an optimum level of fat. Optimum slaughter weight has been defined as the weight at which a specified ratio of lean : fat is reached in the carcass (Jackson, Weddell and Mansour, 1974; Berg *et al.*, 1978) or at which the subcutaneous fat depot represents a given proportion of the carcass (Knapman, 1976; Croston, Jones and Kempster, 1979). For the purposes of this discussion, optimum slaughter weight was defined as the liveweight at

which the carcass contained 12% subcutaneous fat. This level of subcutaneous fat in the carcass corresponds approximately to Fat Class 3L of the MLC Lamb Carcass Classification Scheme (A.J. Kempster, personal communication). The optimum slaughter weights were determined graphically using the common regression slopes of subcutaneous fat on side weight and of side weight on liveweight.

Estimates of the optimum slaughter weight for each sire breed are presented in Table 7.17. Estimates of mature size of the pure breeds are derived from the mean pre-mating weights of ewes of over two years of age measured in MLC Performance recorded flocks (J.L. Read, personal communication). The recorded means were multiplied by a factor of 1.1 to adjust for the sex of lamb. Mature size values for the Southdown and Cotswold are taken from Knapman (1976). An average ewe mature size of 67 kg was assumed for the dams of cross-bred lambs (Smith *et al.*, 1980).

The estimates of optimum slaughter weight approximate to the guideline of 50% of mid-parent mature size which is regularly used in extension work. However estimates of the optimum slaughter weight of the Texel and Oldenburg deviate from this pattern. This was related to the low level of fat in these breeds and in the case of the Oldenburg may be exaggerated by an unreliable estimate of mature size and small sample size. Estimates of killing-out percent and carcass composition at these optimum slaughter weights are given in Table 7.18.

Differences between breeds in carcass composition were reduced when adjustment was made to a constant level of subcutaneous fat in the side. Carcass weights and the ranking of the Southdown, Ile de

Table 7.17 Estimates of optimum slaughter weight, mature size and slaughter weight as a percentage of the mid-parent mean

Breed	Slaughter weight (kg)	Mature size (kg)	Mid-parent mean (kg)	Slaughter weight/ Mid-parent (%)
Southdown	32	64	66	48
Dorset Down	39	81	74	53
Ile de France	43	-	-	-
Suffolk	43	92	80	54
Cotswold	45	98	83	54
Oxford	45	98	83	54
Texel	47	90	79	59
Oldenburg	56	72	70	80

Table 7.18 Estimated killing-out percent and carcass composition by breed of sire, with lambs slaughtered when subcutaneous fat represents 12% of carcass weight

Breed of Sire	Killing-out (%)	Lean (%)	Fat (%)	Bone (%)
Southdown	43.8	53.2	28.1	15.1
Dorset Down	43.3	54.2	27.3	15.5
Ile de France	42.7	56.4	25.0	15.6
Suffolk	43.7	54.4	27.3	15.9
Cotswold	42.3	55.3	26.6	16.1
Oxford	43.2	55.4	26.3	16.2
Texel	45.8	57.4	25.9	14.3
Oldenburg	44.7	58.0	24.9	14.3

France, Suffolk and Oxford for this trait were similar to those reported by Cuthbertson and Kempster (1978) for breed comparisons at 11.7% subcutaneous fat in the side. However variability between breeds in carcass composition was greater than they reported. The Texel and Oldenburg tended to have a high % lean whilst the Southdown gave low lean yields. Breed differences in subcutaneous fat : intermuscular fat ratio may be implicated. Although the Southdown had a higher ratio of subcutaneous : intermuscular fat at any side weight than the Texel and Oldenburg differential growth of these fat depots relative to side weight and the high slaughter weights of these two breeds resulted in a higher SF : IMF ratio than in the Southdown. Consequently the prediction of total fat from its relationship with subcutaneous fat may differ between these extreme breeds and thus composition at constant levels of subcutaneous fat will differ. However, differences between the Texel and the Ile de France, Suffolk and Oxford for % total fat were not large and differences in lean : bone ratio are also evident.

7.2.8 Weight loss and compensation

The experimental study of changes in carcass composition associated with body weight loss and compensation are beyond the scope of this thesis. However, fluctuations in liveweight and tissue weights were observed (Tables 7.2 and 7.3), with major tissue weight loss occurring between slaughter groups 8 and 10. Comparisons of the tissue weights found in slaughter group 10 with tissue weights in previous slaughter groups of similar liveweight would suggest that lean and bone content is more stable relative to liveweight than fat content. The results are presented diagrammatically in Figures 7.3

and 7.4 where tissue weights taken from Tables 7.2 and 7.3 are plotted relative to liveweight on a logarithmic scale and following an age sequence. Caution is required in the interpretation of these results as no experimental treatments were applied specifically to investigate the effects of weight loss and compensation and different patterns of liveweight change are apparent in each year of the experiment. However there is general agreement between these results and those of Butterfield (1966) who found that weight loss and compensation in steers resulted in animals with lower killing-out percent and higher lean : fat ratio relative to unrestricted controls of equal liveweight.

The results of experiments designed to investigate weight loss and compensatory growth are equivocal both in terms of the relative importance of the fat and lean as components of weight loss and comparisons of the composition of realimented and continuously grown animals of similar liveweight (Meyer and Clawson, 1964; Kellaway, 1973; Little and Sandland, 1975; Thornton, Hood, Jones and Re, 1979). Kellaway (1973) suggested that disparity between experimental findings may be attributed to differences in age when the nutritional restriction was applied, its duration and severity, and the duration of the period of compensatory growth. Thornton *et al.* (1979) suggest that in mature animals the weight of fat lost will be greater than the weight of lean lost. In immature animals the lean tissue may be the major source of carcass weight loss, but in both groups of animals a greater proportion of fat than lean would be lost.

Figure 7.3 Slaughter group means for $\log_{10}$ lean, fat and bone weights plotted, following an age sequence, against group means for $\log_{10}$ liveweight (1976/1977)

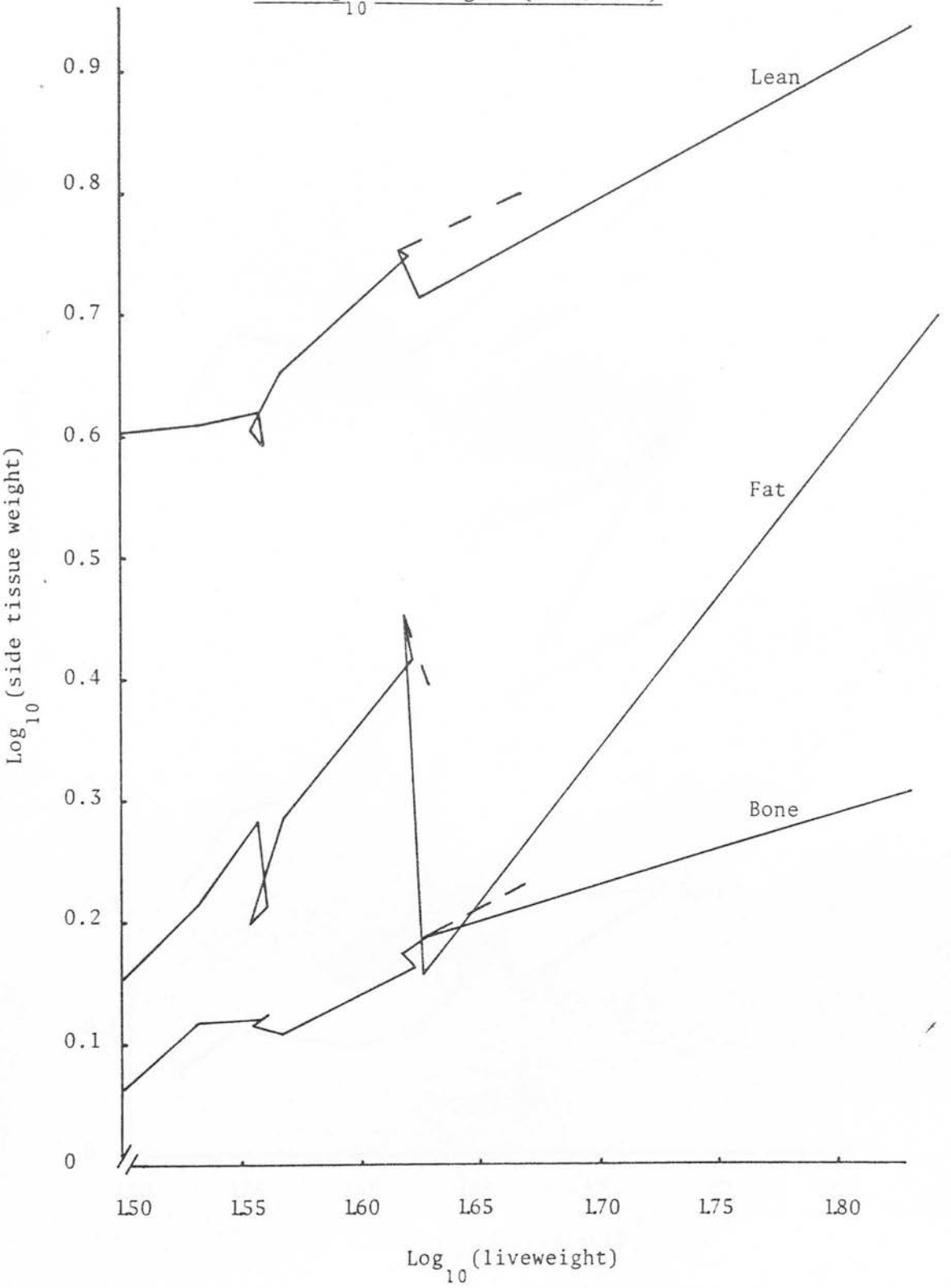
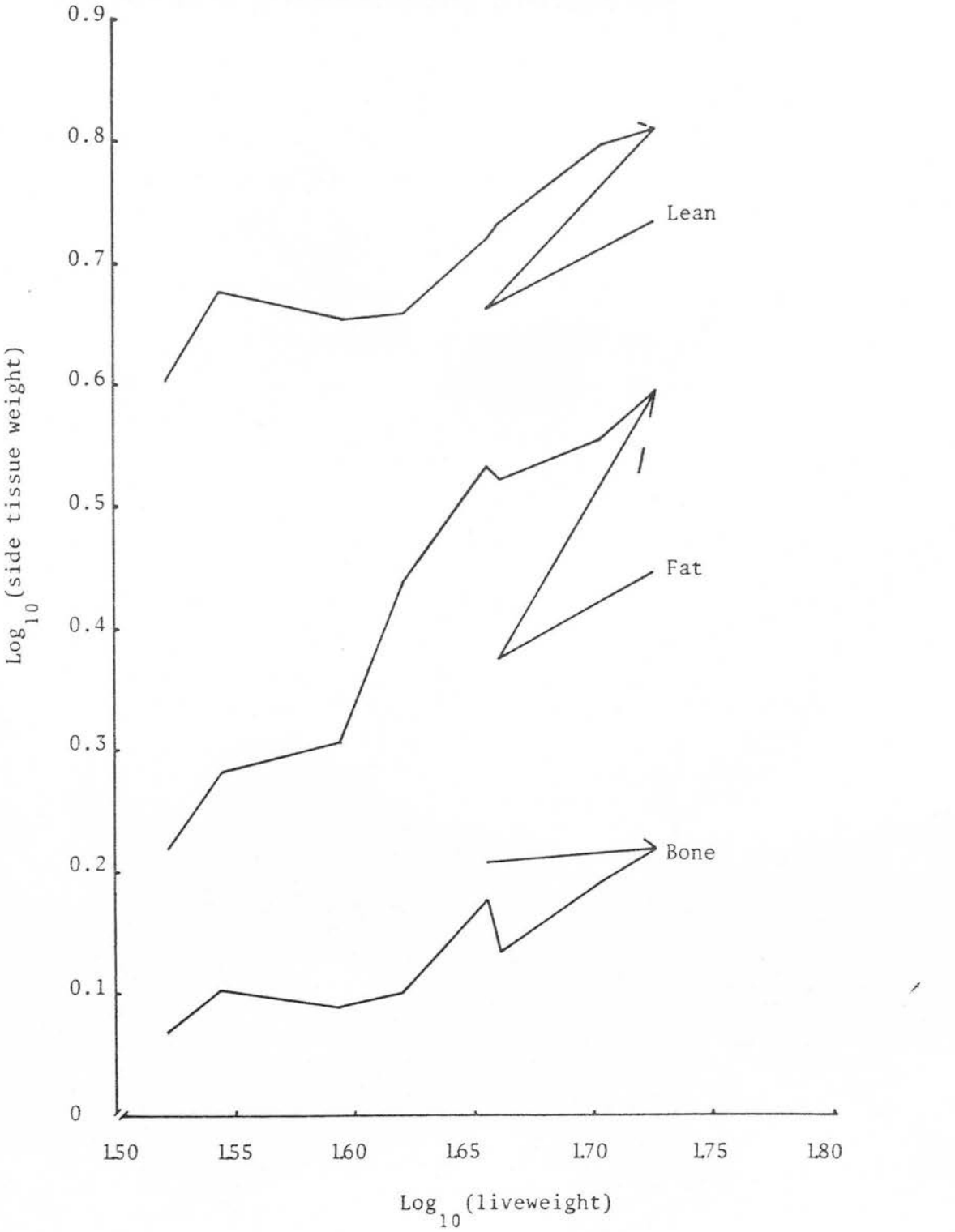


Figure 7.4 Slaughter group means for $\log_{10}$ lean, fat and bone weights plotted, following an age sequence, against group means for $\log_{10}$ liveweight (1977/1978)



The results for weight loss from individual fat depots show a similar trend to those of Russel, Gunn and Doney (1968) and Little and Sandland (1975) who reported that the subcutaneous fat depot was most severely depleted during liveweight loss.

CHAPTER 8

FINAL DISCUSSION AND CONCLUSIONS

Firm statements about the effects of factors included in the analytical models can only be made in the absence of significant interaction terms. In the analysis of the Fixed Slaughterweight data it was assumed that the environmental factors fitted in the model combined in an additive fashion and only interaction terms which were critical to the validity of the statistical model or which were considered likely to affect the interpretation of the sire breed effect were tested. Subsequently, in the analysis of the Serial Slaughter data, a range of interactions of environmental factors were rigorously tested and found to be unimportant. The following discussion therefore concentrates on interaction terms involving breed of sire.

The breed of sire × year interaction was significant only for a limited number of pre-weaning growth traits in the Fixed Slaughterweight Trial. It is usual to interpret this term as a genotype × environment interaction. However, a direct interpretation of this type is not strictly possible, since in this trial different sires were used in each year. When years were classified as either 'high' or 'low' according to the mean level of performance for a given trait, the sire breeds did not rank consistently between years within the same class. The importance of this interaction therefore remains open to interpretation. The lack of significant sire breed × year interactions for slaughter age and carcass traits would suggest that the ranking of breeds reported in this study would hold for a range of different farm environments.

Vesely *et al* (1977) considered that specific combining ability for growth traits was unlikely to be important. The lack of significant interactions of sire and sire breed with breed of dam supports this conclusion and extends it to carcass traits, although only a limited range of dam breeds was used. The implication is that selection within purebred Down breeds may be made without reference to the breed of dam. Some evidence to the contrary has been presented by Bowman and Broadbent (1966) and Geenty *et al* (1979) who found a significant sire × breed of dam interaction for carcass weight at constant liveweight.

The sire breed × slaughter group interaction term was not significant for any of the slaughter or carcass traits studied in the Fixed Slaughterweight Trial. This result is in agreement with those of More O'Ferrall and Timon (1977b) for a similar selection of sire breeds studied over a similar weight range.

In the Serial Slaughter Trial no significant differences were found between breeds for the allometric coefficients for the growth of carcass tissues relative to a number of independent variates. The interpretation of this result is that either breed differences in differential growth of the carcass tissues did not occur or could not be detected in this experiment over the weight range studied. Significant between breed differences in intercept suggest that differential tissue growth has occurred at some stage prior to the start of the experiment. The size and structure of the data set and the evidence for breed differences in differential tissue growth presented in Section 2.2.3 leads one to ask whether biologically important differences have been obscured by the statistical methods

used. However, when individual regression slopes were fitted for each breed at higher levels of the analysis no significant breed differences were found. The effects of the different environmental factors upon the regression slopes were less clear since with larger numbers some significant effects were found. The significant difference between years for the differential growth of lean relative to liveweight was consistent with the results of Boccard and Dumont (1970). Similarly, the significant effect of rearing-type on the differential growth of fat depots relative to liveweight was consistent with trends noted by Wilson (1975). The use of individual regression slopes in these analyses might have slightly altered the conclusions about the differences between year and rearing-type effects estimated at the mean of the independent variate. However, breed means were unbiassed by the use of common regression slopes.

The breed comparisons for liveweight growth traits were similar in both trials although breed differences for pre-weaning growth traits did not reach significance in the Serial Slaughter trial. The Oxford and Suffolk had the highest growth rates to twelve weeks and slaughter at constant weights and were heaviest at constant slaughter age. Small differences in growth traits were observed for the other breeds and although the Texel tended to be lightest at twelve weeks there were no significant differences recorded for slaughter age at constant weight, or weight at constant age.

Significant differences were found between sire breeds for killing-out percentage and carcass composition. The Southdown, Dorset Down and Texel crosses had relatively high killing-out percentages and lean : bone ratio. However, the Southdown and Dorset Down crosses had

growth patterns typical of early-maturing breeds with high levels of fat in the carcass whereas the Texel cross was late maturing with above average carcass leanness. These characteristics of the Texel cross have also been noted by More O'Ferrall and Timon (1977b). In comparisons at constant liveweight the Oxford and Suffolk crossbred lambs did not differ significantly for killing-out percentage or percentage carcass composition, although in both trials the Oxford showed a non-significant tendency to contain less fat in the carcass and lower lean : bone ratio. The low lean : bone ratio of the Suffolk cross is consistent with the results of Kempster and Cuthbertson (1977), More O'Ferrall and Timon (1977b) and Croston *et al* (1979). Comparisons at constant age (Table 7.5) showed that the liveweight and carcass growth rates of the Cotswold cross were significantly lower than those of the Oxford. However, at constant weights the Cotswold and Oxford crosses did not differ significantly for carcass traits and therefore the more numerically scarce Cotswold breed has little to recommend its reintroduction as a sire of meat lambs. Similarly the Ile de France and Oldenburg had little to recommend their substitution for the Suffolk.

McClelland and Russel (1972) proposed that when breeds of different mature size were slaughtered at the same degree of maturity they would contain a similar level of percentage fat in the body. A later investigation gave some support to their hypothesis although extreme breeds were shown to exist (McClelland *et al*, 1976). Similarly, between breed variation in percentage fat in the carcass was reduced when comparisons were made at equal degree of maturity. Conversely breed comparisons made at equal finish might be expected

to be more nearly equivalent to comparisons at equal degree of maturity although extreme breeds may be found. This is supported by the limited data available from this study (Tables 4.6 and 7.17) in which slaughter weights at a constant level of subcutaneous fat were close to 50% of the mid-parent mean mature weight. Both studies showed that the Oldenburg and Texel would require higher slaughterweights than predicted from the mid-parent mean. This deviation may be due in part to inaccurate estimates of the mature size of the purebreeds but is also related to the late development of the fat depots relative to carcass and lean weight and a high ratio of subcutaneous : intermuscular fat at slaughter.

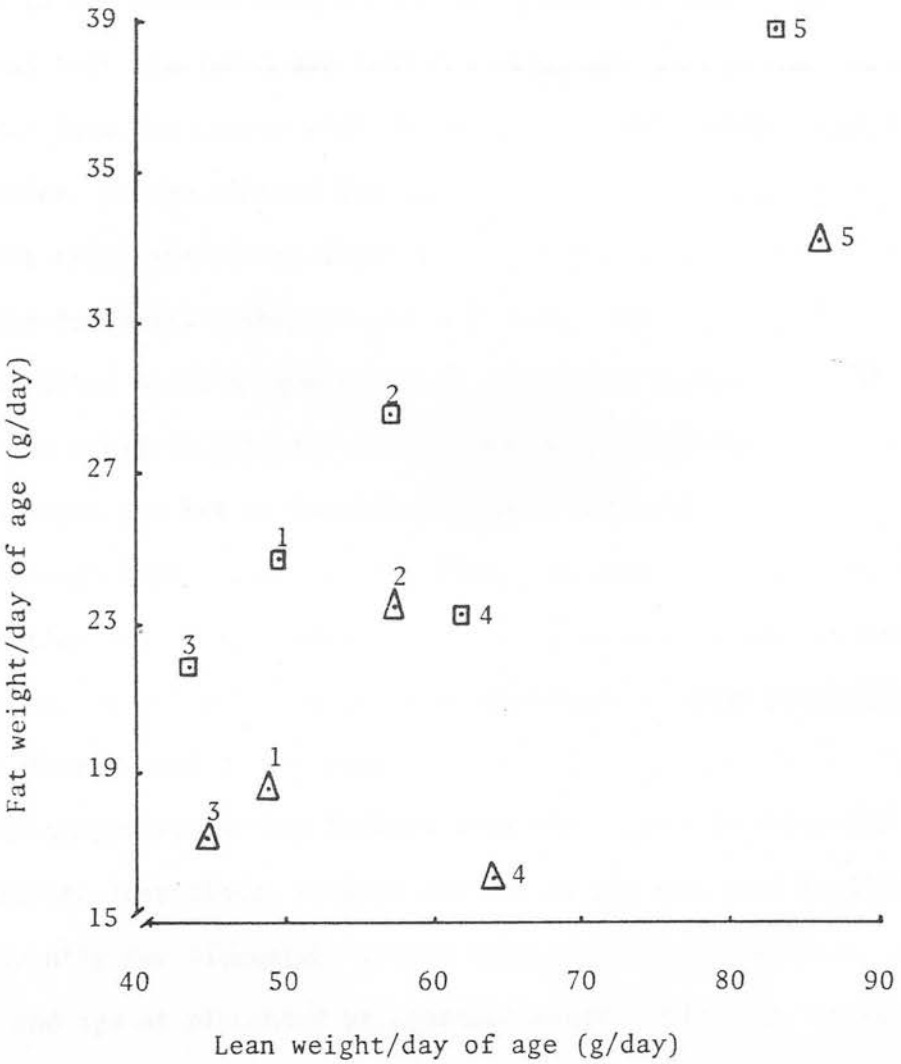
McClelland *et al* (1976) also reported that between 40% and 70% of estimated mature size a wide range of breeds contained a constant 28.5% total muscle in the fleece free empty body. Figures for lean weight at a constant liveweight (Table 7.8) suggest that the Oldenburg and Texel may differ from other breeds in having a higher percentage of carcass lean in the liveweight. Differences in the weights of non-carcass components, which were not studied in these trials, may be implicated. Latif and Owen (1980) reported that both fleece and feet were heavier in the Texel cross than in the Suffolk cross in comparisons made at constant liveweight.

The comparison between the Suffolk and the Texel is particularly interesting because they have similar expected mature size, yet differ markedly in liveweight growth rate and carcass composition. In all comparisons of these sire breeds the Suffolk has been younger at constant slaughterweights or heavier at constant age (More O'Ferrall and Timon, 1977a; Latif and Owen, 1979 and 1980; and Tables 4.4, 4.5

and 7.5 of this study). In each comparison the Suffolk and Texel were shown to have very similar lean tissue growth rates (as measured by the weight of lean per day of age) and the slightly higher values of the Suffolk for carcass weight per day of age were almost entirely explained by its greater rate of fat deposition (measured as weight of fat per day of age). Estimated values of weight of fat per day of age plotted against weight of lean per day of age for each experimental comparison of the Suffolk and Texel are shown in Figure 8.1. McClelland (1975) suggested that the Texel may have a limited appetite which allows maximum muscle development, but restricts the deposition of fat which has a lower priority for growth. A comparison of data from studies 4 and 5 (Figure 8.1) suggests that under grazing conditions up to about 34 kg liveweight, neither breed has achieved maximum lean tissue growth rate. Limited information, taken from small experiments, suggests that the Texel has similar daily intakes of concentrate diets as the Suffolk for liveweight growth ranges from 18 to 32 kg (Hanrahan, 1979), and between 13 and 34 kg (Latif and Owen, 1980). An alternative suggestion therefore, is that the Texel may differ in either maintenance requirement, heat loss related to growth or efficiency of the digestive tract. However, although differences in rates of carcass fat deposition may explain the differences between these breeds in carcass weight per day of age, they do not entirely explain the differences in liveweight growth rates, which were approximately twice as large.

In practice, small, early maturing breeds such as the Southdown and Dorset Down may be suitable for the production of light weight carcasses in early lamb production off grass. Where early lamb

Figure 8.1 Experimental comparisons of the Suffolk ⊡ and Texel △ for lean tissue and fat weights/day of age



1 More O'Ferrall and Timon (1977b)

2 Constant slaughter weight (Table 4.4)

3 Constant age (Table 7.5)

4 Latif and Owen (1979)

5 Latif and Owen (1980)

production is based upon concentrate diets, breeds of larger mature size and rapid growth rate, such as the Suffolk and Oxford, may deposit satisfactory levels of fat relative to muscle to produce a finished carcass in the limited time available. Latif and Owen (1980) have suggested that the Texel may also be useful for this production system, but their data, in common with the results of this study, suggest that the heavier, leaner carcass may take longer to produce. A similar criticism of the Texel is relevant for production systems which aim to finish lambs off grass in early summer. The Texel should be used either where a premium which covers the costs of the longer production cycle is paid for the leaner carcass, or in production systems which are not so heavily dependent upon rapid, early growth.

Although significant breed differences were found in lean tissue distribution their importance in selecting between breeds is likely to be small relative to the larger differences in lean production, overall fatness and growth rate.

The comparison of the Suffolk with the Texel, in which two breeds with similar lean tissue weights per day of age are seen to differ significantly for liveweight growth rate, lean : bone and lean : fat ratios and age at slaughter at constant weight or finish, serves to underline the complexity of selection objectives for terminal sire breeds of sheep. Of the possible selection objectives only liveweight growth traits are easily measured on the live animal. However, the low heritability estimates of early liveweight growth traits found in this study were consistent with previously published estimates for terminal sire breeds used in crossbred lamb production (Bichard and Yalcin, 1964; Bowman and Broadbent, 1966; Bowman, 1968; Bowman and

Hendy, 1972). Results of this type lend support to further investigations of methods of increasing the heritability by reducing environmental variation (Owen *et al*, 1978) or alternatively, selection for correlated characters such as weights at later ages, which are more highly heritable. In contrast highly reliable estimates of 0.19±0.03 have been made for the heritability of eight week weight (P.R. Bampton, personal communication) in purebred Suffolk flocks. It would therefore appear that the rate of gain expected from specialized testing methods must be compared with predicted rates of gain from direct selection using heritability estimates of 0.15 to 0.20. Furthermore, the increased costs of specialized tests and the length of the generation interval must also be considered.

The percentage lean and fat and the lean : fat ratio in the carcass were moderately heritable but lean : bone ratio, subcutaneous : intermuscular fat ratio and eye-muscle area had low heritabilities. Lean weight per day of age had a high genetic correlation with ADG birth to slaughter (0.95±0.03) which, in the carcass dissection data set, had a heritability of 0.24±0.11. Consequently, selection for liveweight growth rate should be almost identical to direct selection for lean weight per day of age. Preston and Willis (1970) suggested that selection for liveweight growth rate to constant weights would result in animals which were leaner or showed no change in percentage fat in the carcass. Conversely they suggested that selection at constant age would result in a larger and thus fatter carcass. Barlow (1978) in a review of genetic aspects of growth in beef cattle has presented evidence in support of this view. The evidence relating to growth in sheep is scarce and estimates of genetic correlations

between traits are generally unreliable. However, average daily gain to slaughter at a fixed weight had genetic correlations of -0.25±0.23 with fat weight and of zero with fat depth (Botkin *et al*, 1971). Average daily gains to a constant slaughter age were negatively correlated to fat depth but positively correlated to percentage kidney fat in the carcass (Olson *et al*, 1976). Field, Kemp, Varney, Woolfolk and Derrickson (1963) selected sires on a 120 day test starting at 180 days of age. The crossbred progeny of high growth rate rams were leaner when slaughtered at a constant weight. Pattie and Williams (1966) reported that lambs from a flock selected for high weaning weight were fatter at a constant age than lambs from a line selected for low weaning weight. Although many of the estimates of genetic correlation presented in this study have high standard errors the general trend in the data suggests that selection for liveweight growth rate or lean weight per day of age would give a correlated reduction in percentage fat in all depots, increased percentage lean, percentage bone and eye-muscle area and reduced lean : bone ratio.

Eye-muscle area and subcutaneous fat depth have been investigated as predictors of carcass composition in the live animal. The phenotypic correlations between fat depth and carcass traits were generally higher than the phenotypic correlations with eye-muscle area. The lower genetic correlation of eye-muscle area with percentage lean, its lower heritability and lower coefficient of variation, coupled to a higher cost of estimation, makes the use of eye-muscle area in a selection index relatively less attractive than subcutaneous fat depth.

The analyses of tissue distribution indicated that direct selection to change lean tissue and subcutaneous fat distribution would be possible. The genetic correlations between lean weight per day of age and tissue distribution traits suggested that selection for rapid growth would give correlated changes in tissue distribution which were not entirely consistent with the patterns of differential growth of the tissue. In other words, it may be possible to change tissue distribution independently of stage of maturity of the tissue. However, this interpretation is debatable since many of the genetic correlations were estimated with high standard errors, but it is consistent with the finding that breed differences in tissue distribution at constant total weights of tissue are not entirely dependent upon differences in the stage of maturity when the comparisons were made.

The two trials showed consistently higher liveweight growth rates in wethers than in females, the wethers being approximately 0.3 kg, 1.5 kg and 2 kg heavier at birth, 12 weeks and 35 weeks of age respectively. In comparisons made at constant liveweights of approximately 40 kg neither trial showed a significant effect of sex on side weight but females tended to be more mature with a higher percentage fat and higher lean : bone ratio than wethers. All fat depots were significantly greater in the female in the Fixed Slaughterweight Trial but only subcutaneous fat was significantly affected in the Serial Slaughter Trial. Although individual regressions slopes were not fitted for each sex in the final analyses of the Serial Slaughter data the growth of fat depots relative to all independent variates tended to be higher in females than in wethers, the reverse trend being apparent for the lean tissue. These trends are consistent with the results presented by

Fourie *et al* (1970). Seebeck (1966) pointed out that allometric analyses of serial slaughter data give equal weight to early and late points and suggests that the effect of sex upon the regression slope may often be underestimated. However, males may reach puberty at weights ranging between 25 kg and 38 kg (35 to 45% of mature size) (Lees, 1978) and it is therefore unlikely that this factor has had a serious effect upon the results of this study. Comparison of the sexes at constant finish showed that wethers would be 1.25 kg heavier at slaughter but similar in age and carcass composition to females.

The results of the analysis of lean tissue distribution were in agreement with previously published results which suggested that castration does not entirely remove the distinctive male muscle development in the shoulder and neck (Seebeck, 1968; Jury *et al*, 1977; Taylor *et al*, 1980). Consequently wether lambs tend to have a lower proportion of total lean in the higher-priced cuts when compared at constant weight of total lean. Slaughter at constant finish might be expected to increase the difference between sexes in lean tissue distribution, but the difference is unlikely to have great economic importance when the value of the total lean production is considered. Sex of lamb had a similarly small, but significant effect ($P < 0.05$) on the distribution of subcutaneous fat.

The effects of ewe age upon the liveweight growth of lambs were consistent with previous reports, e.g. Yalcin and Bichard (1964), in showing an increase in weights for age and average daily gains with increasing ewe age. The size of the effect of ewe age differed between the two trials, although both sets of results suggest that lambs reared by younger ewes may approach the growth rates of lambs

reared by older ewes as their dependence on the mother declines. However, in the Serial Slaughter Trial a difference of 2 kg between the progeny of two year-old and three year-old ewes which was established at eight weeks of age, remained unchanged at thirty-five weeks and it therefore seems unlikely that the lambs which have suffered an early disadvantage have exhibited compensatory growth in later life. The increased fatness of lambs reared by older ewes, which was observed in the comparison at constant liveweight in the Fixed Slaughterweight Trial, was largely related to variation in side weight. In practice, when lambs are slaughtered at similar weights and finish, the major effects of ewe age would appear to be in an increased age at slaughter for lambs reared by younger ewes. Although this effect was most marked for the comparison of one year-old ewes with older ewes in the Fixed Slaughterweight Trial, the difference of 16 days in age at slaughter recorded between the progeny of two year-old and three year-old ewes could be commercially important and was similar to the age difference found between the progeny of Texel and Suffolk sires.

The effects of rearing-type on liveweight growth were similar in both sets of data. Differences between singles, twins and triplets in birthweight closely approached those predicted by the model of Dickinson *et al* (1962). A difference between singles and twins of between 1 kg to 2 kg at birth rose to about 6 kg to 8 kg at twelve weeks. The growth rates of twins and triplets tended to approach those of single lambs as weaning approached. In the Serial Slaughter data the difference in weight between singles and twins at twelve weeks was only slightly reduced by thirty-five weeks and it would appear from this that twin lambs did not achieve growth rates which were greater than those of singles in the post-weaning period.

The effect of rearing-type upon carcass composition was not consistent between the two sets of data studied. Twins grew faster to constant liveweights and were fatter in both studies. However, in the Fixed Slaughterweight data differences due to rearing-type were related to differences in side weight, whereas in the Serial Slaughter Trial singles remained fatter than twins at constant side weight. The reasons for this discrepancy are not clear. Adjustment to the mean side weight using different regression slopes for each rearing-type leads to similar conclusions. Regression of the Fixed Slaughterweight data to a constant level of subcutaneous fat suggested that differences in carcass composition due to rearing-type would be negligible but economically important differences in slaughter age and carcass weight would remain.

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APPENDIX 1

DESCRIPTION OF DISSECTION PROCEDURES

APPENDIX 1

Carcass dissection procedures

The half carcass was subjected to a standard physical dissection procedure in which the left-hand side was cut into eight standard joints using anatomical reference points. Each joint was separated by butchers knife into lean, subcutaneous fat, intermuscular fat, bone and waste. A summary of the procedure (described by R.J. Smith, 1970, unpublished mimeograph) is given below.

Kidney Knob and Channel Fat: This was removed as one, the posterior edge of the channel fat in the pelvic cavity being defined by a line running along the posterior border of the sacro-sciatic ligament.

Breast and Leg: Pins were placed on the anterior edge of the 12th rib at the most ventral point of attachment with the diaphragm and in the intercondyloid fossa of the femur. With the side hanging the two pins were joined by a line on the lateral surface. Then, with the side lying on a bench, the leg was marked down to the level of this line by drawing a second line between the ventral posterior edge of the 1st caudal vertebra and a point on the pelvic bone one fifth of the distance between the ventral posterior edge of the last lumbar vertebra and the anterior edge of the symphis pubis. The side was rehung and with a knife held at right angles to the lateral surface a cut was made from the anterior edge of the 12th rib caudally to the line of the leg. With the side lying the leg was removed, thus freeing the posterior part of the breast. The anterior part of the breast up to the rib level with the centre of the 6th

thoracic vertebra was marked by drawing a line from the previously marked point on the 12th rib to the anterior ventral junction of the bone and cartilage on the 1st rib. Any thoracic fat adhering inside the thoracic cavity was removed and weighed, then the breast and fore were removed from the rib level with the centre of the 6th thoracic vertebra forward by cutting from the medial surface and at right angles to it from the posterior edge of the costochondral junction of the rib level with the centre of the 6th thoracic vertebra to the anterior dorsal edge of the 2nd sternebra.

Chump: This was removed from the side by a cut at right angles to the long axis of the last lumbar vertebra between the penultimate and last lumbar vertebrae.

Loin: This was separated from the best end neck by marking the centre of the 12th thoracic vertebra and, with a knife held at right angles to the medial cut surface of the vertebral bodies and spines and at right angles to the long axis of the 12th thoracic vertebra, sawing and cutting until the posterior edge of the rib was hit. Then the curve of the rib was followed until the line of the breast was met. The loin was divided into two by a cut through the centre of the 3rd lumbar vertebra with the knife held at right angles to its long axis and at right angles to the medial cut surface of the ventral bodies and spines.

Best End Neck: This was separated from the rest of the fore by cutting and sawing through the centre of the 6th thoracic vertebra, with the knife held at right angles to the medial cut surface of the vertebral bodies and spines and parallel to the cut at the level of the 12th thoracic vertebra. The posterior edge of the rib was

followed after contact with the knife held at right angles to the medial surface of the ribs. A photograph was taken on the posterior face of the joint at the level of the centre of the 12th rib.

Neck (or Scrag): This was removed from the shoulder and middle neck by sawing and cutting along the anterior edge of the 4th cervical vertebra with the knife held at right angles to the medial surface of this vertebra and at right angles to its long axis.

Shoulder and Middle Neck: These were separated by starting on the anterior medial face of the M. scalenus ventralis and, working laterally, on to the 1st rib, finding the natural separation in fat between the shoulder muscles and M. serratus ventralis. The M. trapezius was left on the shoulder but the M. rhomboideus and M. serratus ventralis were left on the middle neck.

Tissue Separation

The tissues separated were defined as follows:-

Lean: Bone was excluded from separable lean, but where the periosteum was not firmly attached to the bone it was included with the lean. Small blood vessels, connective tissue sheaths and small quantities of fat which were physically difficult to separate also contributed to the weight of lean.

Subcutaneous fat: The external fat down to the level of the connective tissue over the peripheral muscle layer (which was defined to exclude the M. cutaneous muscle which lies in the subcutaneous fat). For the hind and fore limbs the fat under the external connective tissue sheath down to the level of the connective tissue adhering to the peripheral muscles was classed as subcutaneous.

Intermuscular fat: The fat lying between the muscles, together with thin connective tissues, small blood vessels and small quantities of muscle that were physically difficult to separate.

Bone: This included cartilage together with small quantities of muscle, fat and other tissues which were physically difficult to separate. Vertebral bone, including the sacrum, was weighed and recorded separately to other bone.

Waste: This consisted of all glands, all major blood vessels which could be easily separated from the surrounding tissues and tendons of the lower leg muscles which were cut off at right angles to the line of the tendon at the most distal part of the muscle belly. The ligamentum nuchae was included in this category.

APPENDIX 2

EXAMPLES OF ANALYSES OF VARIANCE (FIXED SLAUGHTER WEIGHT TRIAL)

Table A.2.1 Analysis of variance for twelve week weight - taken from the fixed effects model 1 (see Table 3.4)

	d.f.	Sums of squares	Mean square	F-ratio
Sire breed	5	118340.0	23668.2	18.5 ***
Year	4	155651.8	38912.9	30.4 ***
Sire breed × year	20	74962.9	3748.1	2.9 ***
Dam breed	1	43058.1	43058.1	33.6 ***
Dam age	2	743192.7	371596.3	290 ***
Birth-rearing type	6	2353958.0	392326.3	306 ***
Dam breed × sire breed	5	6285.5	1257.1	1.0 NS
Dam breed × year	4	15092.1	3773.0	2.9 *
Date of birth	1	17836.5	17836.5	13.9 ***
Age deviation	1	78531.3	78531.3	61 ***
Lamb sex	1	134902.7	134902.7	105 ***
Residual	2534	3248600.7	1282.0	(Res. 1)

Table A.2.2 Nested analysis of variance for twelve week weight, derived from output of models 1 - 4 (see Table 3.4)

	d.f.	Sums of squares	Mean squares	F-ratio
Sire breed	5	118341.00	23668.21	11.9 ***
Year	4	155651.80	38912.95	19.6 ***
Sire breed × year	20	74962.94	3748.15	1.89 *
Sire/(Sire breed, year)	72	142818.49	1983.59	(Res. 1-2)
Dam breed	1	41401.92	41401.92	25.8 ***
Dam age	2	713786.40	356893.18	222 ***
Birth-rearing type	6	2146034.00	357672.31	222 ***
Dam breed × sire breed	5	4560.25	912.05	0.6 NS
Dam breed × year	4	13895.47	3473.87	2.2 NS
Date of birth	1	15234.79	15234.79	9.5 ***
Age deviation	1	73997.02	73997.02	46 ***
Dams/sires + (Dam breed × sire)	1416	2276890.01	1607.97	(Res. 2-4)
Lamb sex	1	65973.83	65973.83	83.3 ***
Residual	1046	828892.23	792.44	(Res. 4)
Dam breed × sire[#]	91	128008.28	1406.68	0.9 NS
Dam age	2	662324.10	331162.03	
Birth-rearing type	6	2003342.00	333890.29	
Date of birth	1	13890.29	13890.29	
Age deviation	1	55642.17	55642.17	
Residual	1325	2148881.73	1621.80	(Res. 3-4)

[#]Estimated from Residual 2-3

Table A.2.3 Nested analysis of variance for slaughter age

	d.f.	Sums of squares	Mean squares	F-ratio
Sire breed	5	94348.4	18869.7	8.0 **
Year	3	248634.3	82878.1	35 ***
Sire breed × year	15	59083.9	3938.9	1.7 NS
Sire/(Sire breed, year)	55	129125.0	2347.7	
Dam breed	1	15398.6	15398.6	8.9 **
Dam age	2	407917.5	203958.7	118 ***
Birth-rearing type	6	1002039.0	167006.6	96 ***
Dam breed × sire breed	5	19792.4	3958.5	2.3 *
Dam breed × year	3	17816.8	5938.9	3.4 *
Date of birth	1	37256.5	37256.5	22 ***
Dams/sires	1046	1812812.0	1733.1	
Lamb sex	1	30542.2	30542.2	21 ***
Slaughter group	1	249145.1	249145.1	171 ***
Sire breed × slaughter group	5	6236.7	1247.4	0.9 NS
Residual	754	1072834.0	1461.6	

Table A.2.4 Nested analysis of variance for percent lean in the carcass

	d.f.	Sums of squares	Mean square	F-ratio
Sire breed	5	3444.649	688.9298	24.2 ***
Year	2	1285.580	642.7899	22.5 ***
Sire breed × year	10	245.6597	24.5660	0.86 NS
Sire/(Sire breed, year)	47	1339.8039	28.5065	
Dam breed	1	14.9229	14.9229	1.37 NS
Dam age	2	94.3266	47.1633	4.32 *
Rearing type	2	229.1358	114.5679	10.49 ***
Dam breed × sire breed	5	58.2534	11.6507	1.07 NS
Dam breed × year	2	41.0006	20.5003	1.88 NS
Date of birth	1	0.0200	0.0200	0.00 NS
Dams/sire + (Dam breed × sire)	551	6017.0979	10.9203	
Lamb sex	1	127.2899	127.2899	15.50 ***
Slaughter group	1	350.0276	350.0276	42.60 ***
Sire breed × slaughter group	5	18.6416	3.7283	0.45 NS
Sex × slaughter group	1	1.2770	1.2770	0.16 NS
Residual	319	2623.7912	8.2251	

Table A.2.5 Nested analysis of variance for percent lean in the carcass, analysis including a regression on side weight

	d.f.	Sums of squares	Mean square	F-ratio
Sire breed	5	3498.8	699.77	30 ***
Year	2	398.0	199.01	8.5 ***
Sire breed × year	10	224.5	22.45	1.0 NS
Sires/(sire breed, year)	47	1098.7	23.38	
Dam breed	1	19.6	19.61	2.0 NS
Dam age	2	13.6	6.80	0.7 NS
Rearing type	2	27.4	13.72	1.4 NS
Dam breed × sire breed	5	38.1	7.63	0.8 NS
Dam breed × year	2	62.8	31.41	3.3 *
Date of birth	1	12.5	12.52	1.3 NS
Dams/sires	551	5296.5	9.61	
Lamb sex	1	137.9	137.87	20 ***
Regression on side weight	1	787.9	787.88	116 ***
Residual	325	2213.7	6.81	

Table A.2.6 Nested analysis of variance for percent lean in the carcass, analysis including a regression on percent subcutaneous fat

	d.f.	Sums of squares	Mean square	F-ratio
Sire breed	5	693.5	138.69	31 ***
Year	2	27.5	13.74	3.0 *
Sire breed × year	10	61.6	6.16	1.4 NS
Sire/(Sire breed, year)	47	212.3	4.52	
Dam breed	1	42.1	42.05	12 ***
Dam age	2	5.6	2.78	0.8 NS
Rearing type	2	6.5	3.27	0.9 NS
Dam breed × sire breed	5	21.1	4.22	1.2 NS
Dam breed × year	2	25.1	12.57	3.6 *
Date of birth	1	9.3	9.32	2.7 NS
Dams/sires	551	1936.6	3.51	
Lamb sex	1	1.27	1.27	0.5 NS
Regression on % subcutaneous fat in side	1	2147.8	2147.81	818 ***
Residual	325	853.8	2.63	

APPENDIX 3

EXAMPLES OF ANALYSES OF VARIANCE FOR TISSUE DISTRIBUTION AND SUMMARY OF YEAR EFFECTS

Table A.3.1 Nested analysis of variance for the percentage of total lean in the leg

	d.f.	Sums of Squares	Mean Square	F-ratio
Sire breed	5	50	10	4.1 *
Year	2	121.9	61.0	24.9 ***
Sire breed × year	10	20.0	2.0	0.8 NS
Sires/(sire breed, year)	47	115.2	2.5	
Dam breed	1	0.9	0.9	0.7 NS
Dam age	2	10.9	5.4	3.9 *
Rearing type	2	6.8	3.4	2.4 NS
Dam breed × sire breed	5	1.1	0.2	0.2 NS
Dam breed × year	2	6.6	3.3	3.4 NS
Date of birth	1	4.3	4.3	3.1 *
Dams/sires	551	768.8	1.4	
Lamb sex	1	0.0	0.0	0.0 NS
Regression on lean weight	1	8.1	8.1	7.3 **
Residual	325	359.6	1.1	

Table A.3.2 Nested analysis of variance for the percentage of total subcutaneous fat in the leg

	d.f.	Sums of Squares	Mean Square	F-ratio
Sire breed	5	394.4	78.9	3.2 *
Year	2	140.4	70.2	2.8 *
Sire breed × year	10	105.9	10.6	0.4 NS
Sires/(sire breed, year)	47	1165.1	24.8	
Dam breed	1	61.2	61.2	5.2 *
Dam age	2	31.9	15.9	1.4 NS
Rearing type	2	31.5	15.8	1.3 NS
Dam breed × sire breed	5	79.9	16.0	1.4 NS
Dam breed × year	2	16.9	8.5	0.7 NS
Date of birth	1	20.4	20.4	1.7 NS
Dams/sires	550	6470.6	11.8	
Lamb sex	1	5.8	5.8	0.8 NS
Regression on subcutaneous fat weight	1	570.0	570.0	74.9***
Residual	319	2427.4	7.6	

Table A.3.3 Fitted values for the effects of year on lean tissue distribution

Percentage of total lean weight found in the :	1973	1974	1975
Leg	0.34 ± 0.06	-0.60 ± 0.06	0.25 ± 0.07
Chump	-0.13 ± 0.04	-0.15 ± 0.04	0.28 ± 0.04
Loin	-0.01 ± 0.06	-0.05 ± 0.06	0.06 ± 0.06
Breast	0.74 ± 0.07	0.03 ± 0.07	-0.77 ± 0.07
Best-end neck	-0.13 ± 0.03	0.05 ± 0.03	0.08 ± 0.03
Middle neck	-0.27 ± 0.04	0.42 ± 0.04	-0.15 ± 0.04
Shoulder	-0.43 ± 0.06	0.27 ± 0.06	0.16 ± 0.06
Scrag	-0.11 ± 0.02	0.03 ± 0.02	0.09 ± 0.02

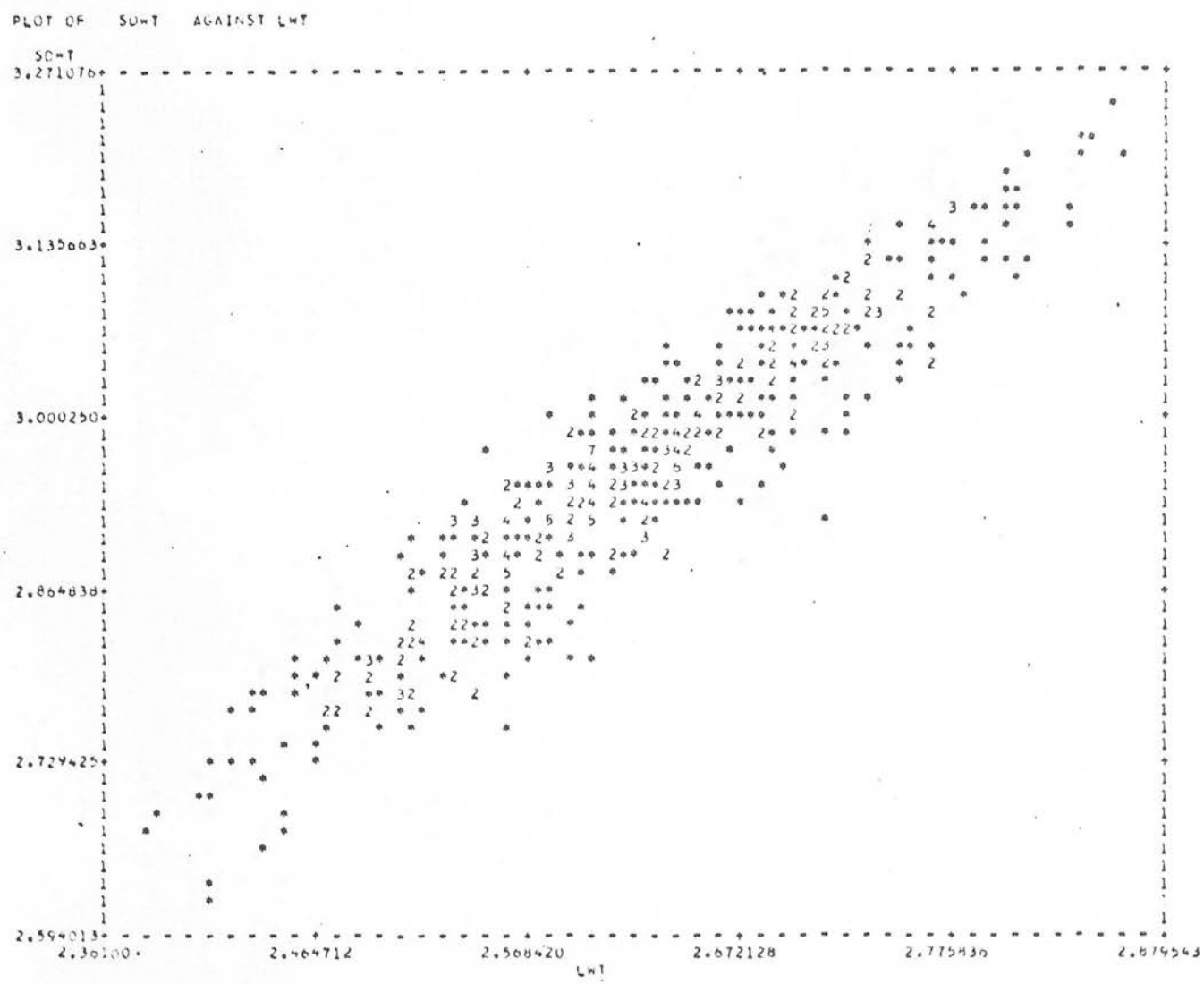
Table A.3.4 Fitted values for the effects of year on subcutaneous fat distribution

Percentage of total subcutaneous fat weight found in the :	1973	1974	1975
Leg	0.34 ±0.19	0.34 ±0.19	-0.68 ±0.19
Chump	-0.37 ±0.09	0.17 ±0.09	0.20 ±0.09
Loin	0.51 ±0.13	0.08 ±0.13	-0.58 ±0.13
Breast	1.63 ±0.18	-0.75 ±0.18	-0.88 ±0.18
Best-end neck	0.63 ±0.11	-0.33 ±0.11	-0.31 ±0.11
Shoulder	-2.04 ±0.20	0.30 ±0.21	1.74 ±0.21
Scrag	-0.70 ±0.06	0.19 ±0.06	0.51 ±0.06

APPENDIX 4

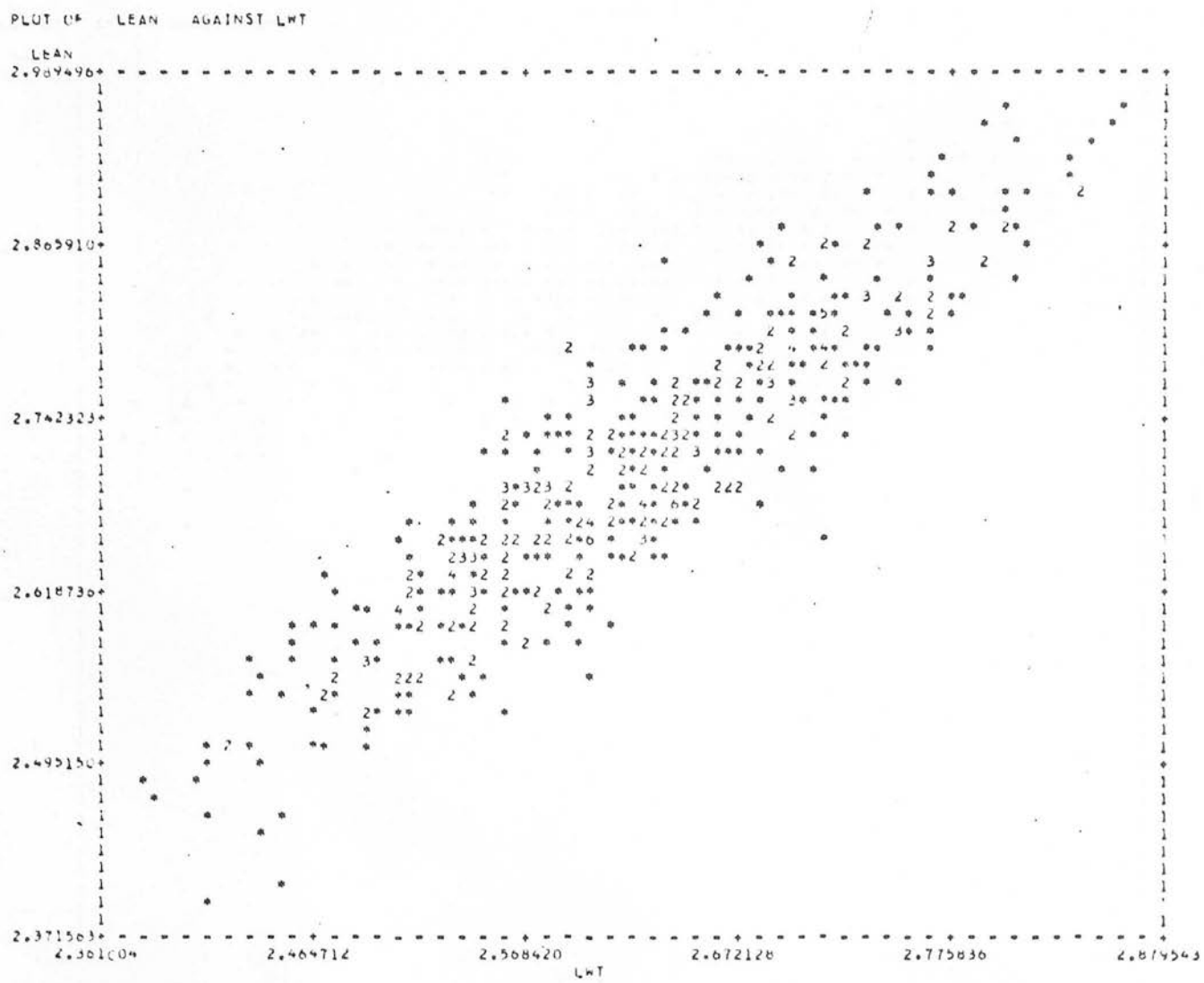
SCATTER DIAGRAMS OF THE RELATIONSHIPS BETWEEN DISSECTIBLE CARCASS TISSUE WEIGHTS IN THE SERIAL SLAUGHTER TRIAL

A.6.1 Plot of $\log_{10}$ side weight (Y) against $\log_{10}$ liveweight (X)



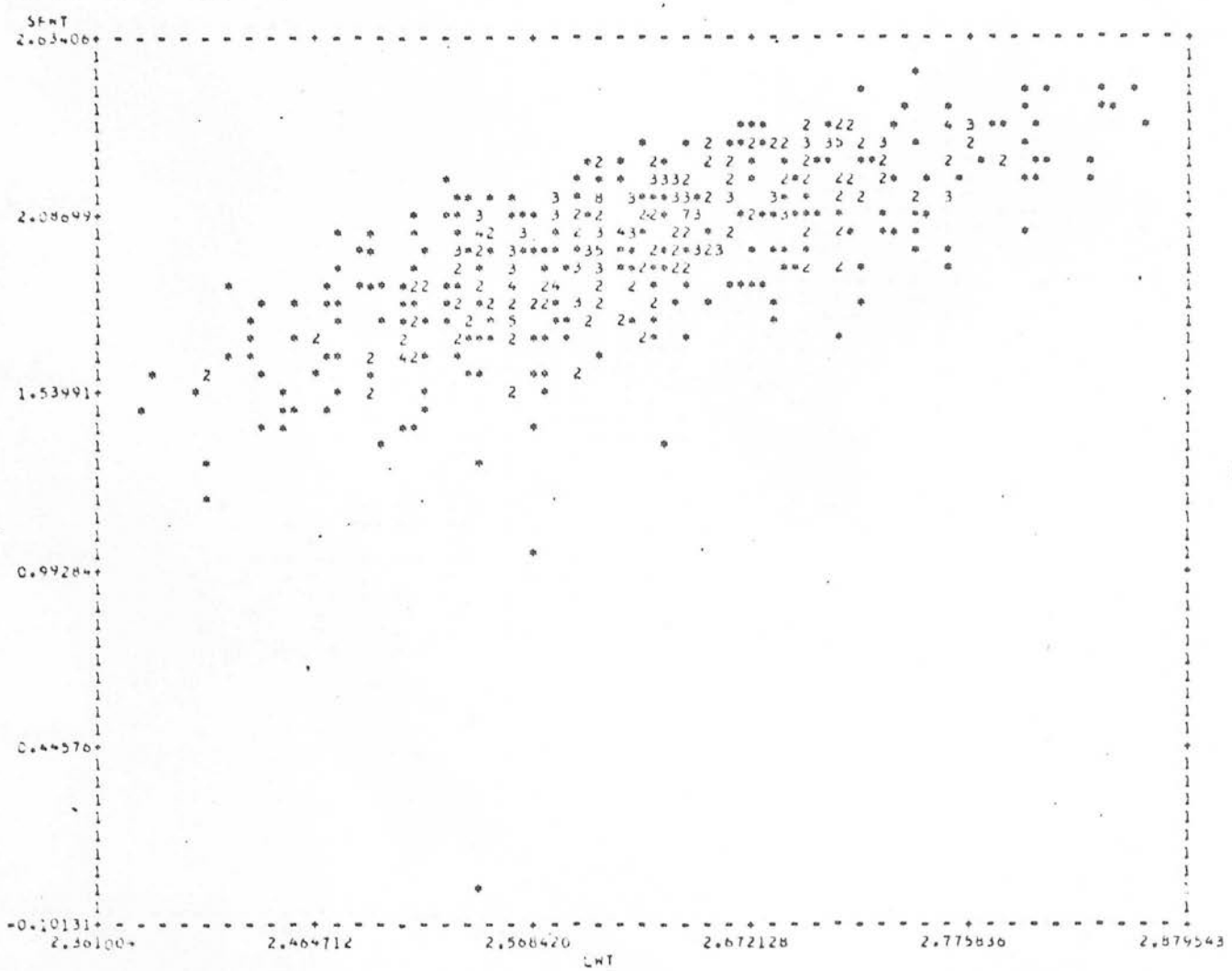
POINTS PLOTTED = 513

A.6.2 Plot of $\log_{10}$ lean weight (Y) against $\log_{10}$ liveweight (X)

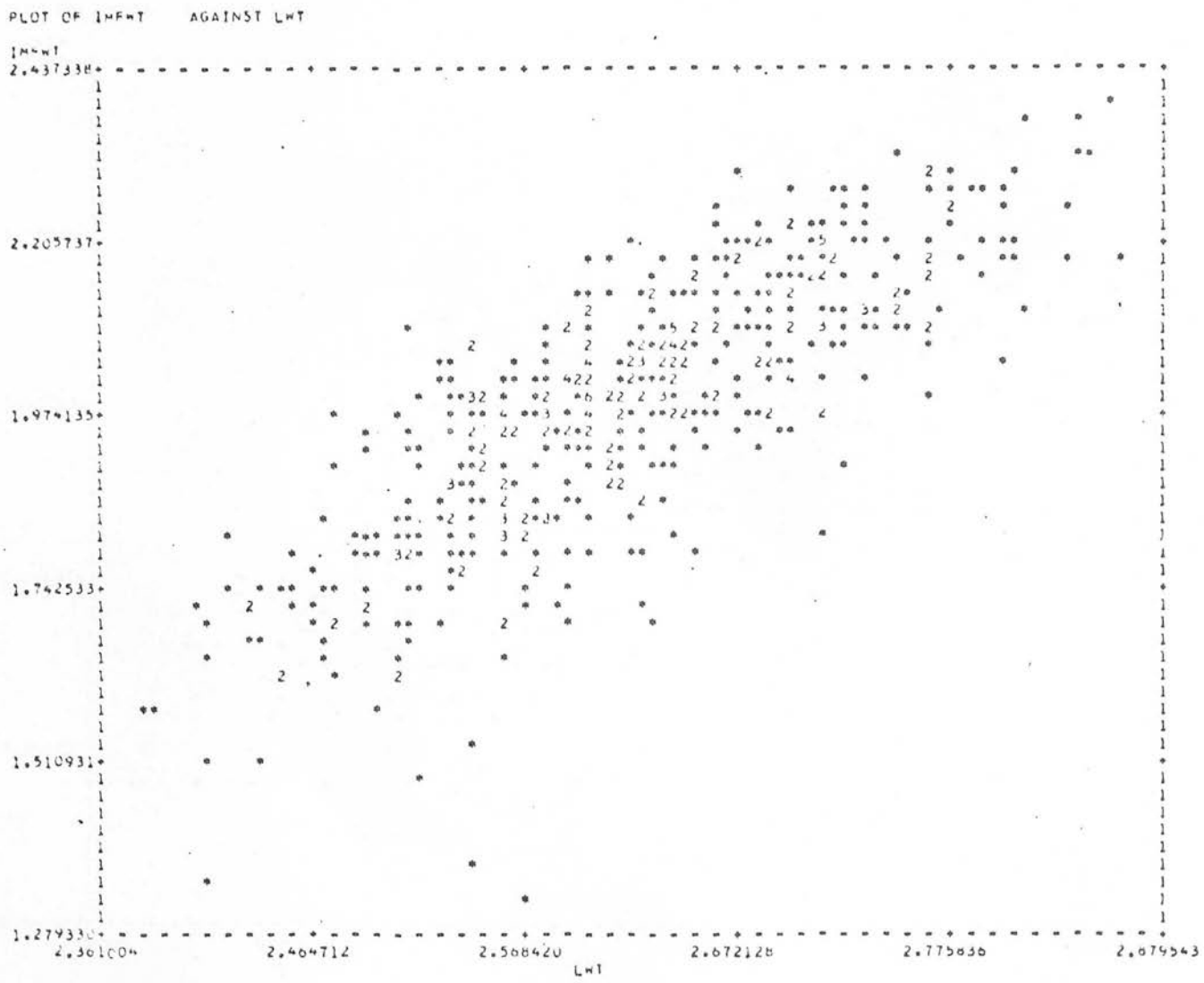


POINTS PLOTTED = 513

A.6.3 Plot of $\log_{10}$ subcutaneous fat weight (Y) against $\log_{10}$ liveweight (X)

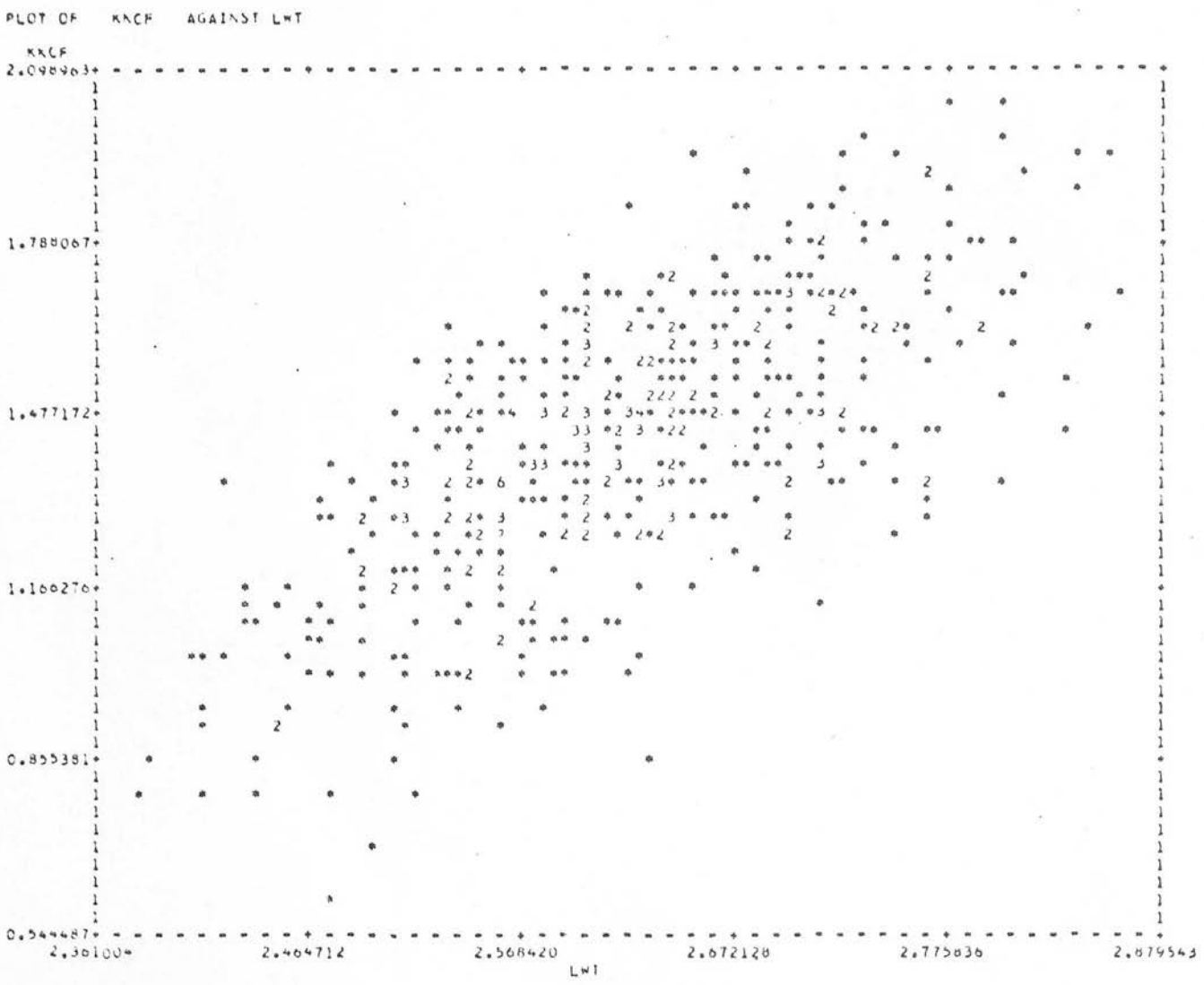


A.6.4 Plot of $\log_{10}$ intermuscular fat weight (Y) against $\log_{10}$ liveweight (X)



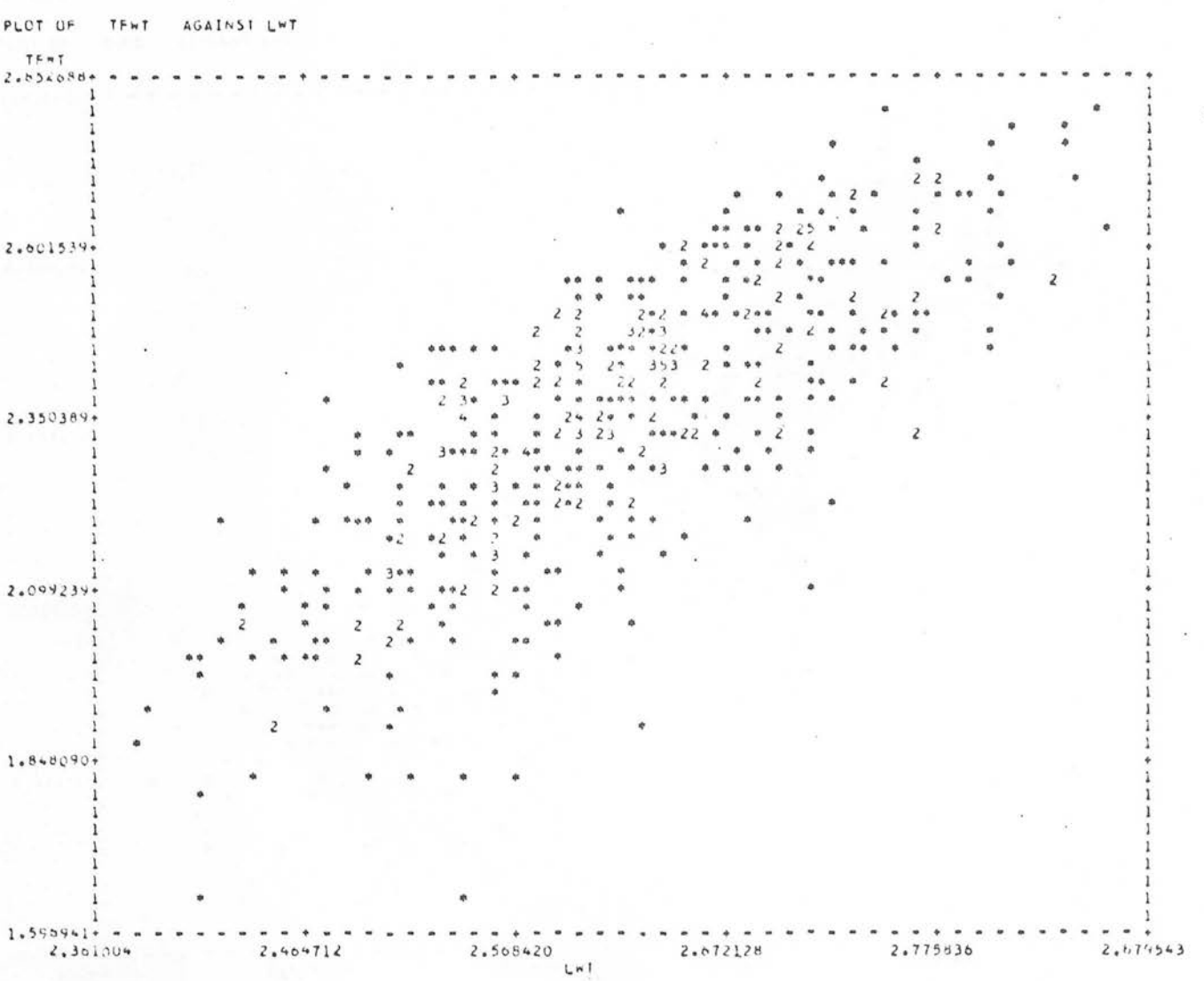
POINTS PLOTTED = 513

A.6.5 Plot of $\log_{10}$ KKCF weight (Y) against $\log_{10}$ liveweight (X)



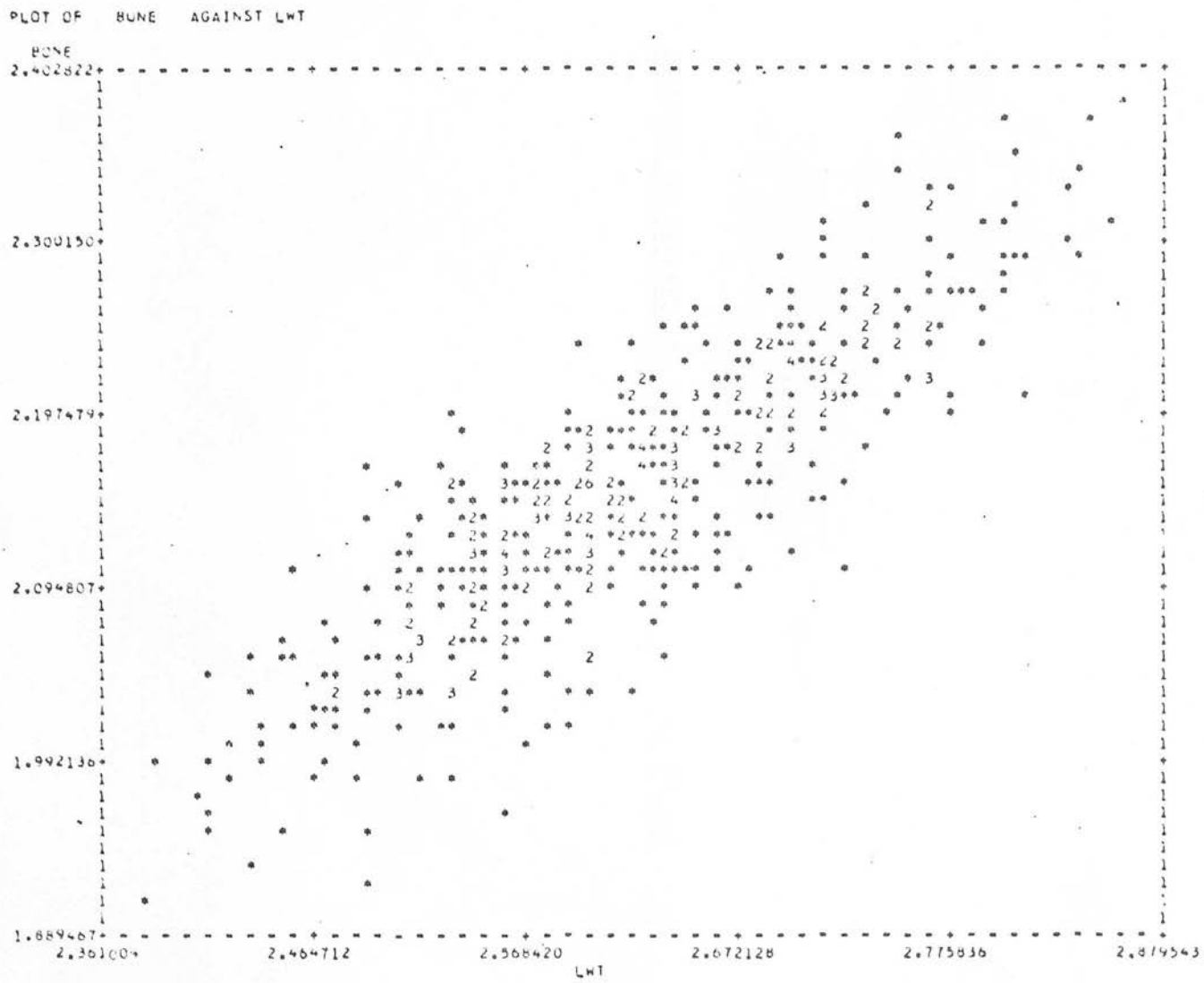
POINTS PLOTTED = 513

A.6.6 Plot of $\log_{10}$ total fat weight (Y) against $\log_{10}$ liveweight (X)



POINTS PLOTTED = 513

A.6.7 Plot of $\log_{10}$ bone weight (Y) against $\log_{10}$ liveweight (X)



POINTS PLOTTED = 513

APPENDIX 5

EXAMPLES OF ANALYSES OF VARIANCE (SERIAL SLAUGHTER TRIAL)

Table A.5.1 Nested analysis of variance for twelve week weight

	d.f.	Sums of squares	Mean squares	F-ratio
Sire breed	7	31840.2	4548.6	2.0 NS
Year	1	103.2	103.2	0.1 NS
Sire breed × year	3	5218.6	1739.5	0.8 NS
Sires/(sire breed, year)	35	79561.5	2273.2	
Dam breed/(sire breed ×year)	32			
Dam age	1	26150.2	26150.2	21.4 ***
Rearing type	1	205350.8	205350.8	168.3 ***
Rearing type × year	1	4521.4	4521.4	3.7 NS
Rearing type × sire breed	7	12601.4	1800.2	1.5 NS
Age deviation	1	19662.4	19662.4	16.1 ***
Dams/sires	284	346599.3	1220.4	
Sex	1	6300.2	6300.2	9.4 **
Residual	138	92242.8	668.4	

Table A.5.2 Nested analysis of variance for lean weight adjusted to a constant age

	d.f.	Sums of squares	Mean squares	F-ratio
Sire breed	7	13.3	1.9	4.5 **
Year	1	0.3	0.3	0.7 NS
Sire breed × year	3	1.5	0.5	1.2 NS
Sires/(sire breed, year)	35	14.6	0.4	
Dam breed/(sire breed ×year)	32			
Dam age	1	4.5	4.5	14.7***
Rearing type	1	10.0	10.0	32.7***
Rearing type ×slaughter group	3	3.6	1.2	3.8 *
Dams/sires	290	88.8	0.3	
Slaughter time	10	17.0	1.7	9.3***
Sex	1	1.5	1.5	7.8 **
Year × slaughter group	3	2.7	0.9	4.7 **
Sire breed × slaughter group	21	4.2	0.2	1.0 NS
Dam breed × slaughter group	9	2.7	0.3	1.4 NS
Residual	95	17.6	0.2	

Table A.5.3 Nested analysis of variance for lean weight adjusted to constant liveweight

	d.f.	Sums of squares	Mean squares	F-ratio
Sire breed	7	8.4	1.2	5.9***
Year	1	0.4	0.4	1.9 NS
Sire breed × year	3	0.9	0.3	1.5 NS
Sires/(sire breed, year)	35	7.4	0.2	
Dam breed/(sire breed ×year)	32			
Dam age	1	0.0	0.0	- NS
Rearing type	1	0.0	0.0	- NS
Rearing type × year	1	0.9	0.9	6.9 **
Rearing type × sire breed	7	1.4	0.2	1.7 NS
Dams/sires	285	38.2	0.1	
Sex	1	0.0	0.0	0.2 NS
Regression on slaughter weight	1	118.3	118.3	778***
Residual	137	20.8	0.2	

Table A.5.4 Nested analysis of variance for lean weight adjusted to constant side weight

	d.f.	Sums of squares	Mean squares	F-ratio
Sire breed	7	7.0	1.0	7.0 ***
Year	1	0.0	0.0	0.1 NS
Sire breed × year	3	1.2	0.4	3.2 *
Sires/(sire breed, year)	35	5.0	0.1	
Dam breed/(sire breed ×year)	32			
Dam age	1	0.1	0.1	1.3 NS
Rearing type	1	2.2	2.2	28.5 ***
Rearing type × year	1	1.1	1.1	13.8 ***
Rearing type × sire breed	7	1.4	0.2	2.9 **
Dams/sires	285	22.1	0.1	
Sex	1	0.0	0.0	0.0 NS
Regression on side weight	1	131.6	131.6	2400 ***
Residual	137	7.5	0.1	

Table A.5.5 Nested analysis of variance for subcutaneous fat weight adjusted to constant lean weight

	d.f.	Sums of squares	Mean squares	F-ratio
Sire breed	7	147.0	21.0	5.7 **
Year	1	9.0	9.0	2.4 NS
Sire breed × year	3	10.8	3.6	1.0 NS
Sires/(sire breed, year)	35	129.2	3.7	
Dam breed/(sire breed ×year)	32			
Dam age	1	1.7	1.7	0.6 NS
Rearing type	1	64.0	64.0	22.4***
Rearing type × year	1	19.3	19.3	6.8 **
Rearing type × sire breed	7	23.1	3.3	1.2 NS
Dams/sires	285	814.3	2.9	
Sex	1	12.8	12.8	4.9 *
Regression on lean weight	1	438.3	438.3	168.6***
Residual	137	357.0	2.6	

APPENDIX 6

ALLOMETRIC COEFFICIENTS ESTIMATED FOR EACH BREED AT DIFFERENT LEVELS OF THE ANALYSIS

Table A.6.1 Allometric coefficients for the regression of carcass weight on liveweight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.16 ± 0.04	1.13 ± 0.02	1.13 ± 0.02
Dorset Down	1.11 ± 0.08	1.12 ± 0.05	1.11 ± 0.05
Ile de France	1.10 ± 0.11	1.21 ± 0.06	1.24 ± 0.06
Oldenburg	1.33 ± 0.12	1.12 ± 0.06	1.12 ± 0.06
Oxford	1.22 ± 0.09	1.15 ± 0.05	1.16 ± 0.05
Suffolk	1.16 ± 0.08	1.16 ± 0.05	1.14 ± 0.05
Texel	1.15 ± 0.09	1.15 ± 0.05	1.10 ± 0.05
Southdown	1.15 ± 0.14	1.12 ± 0.09	1.11 ± 0.09
Cotswold	1.08 ± 0.16	1.00 ± 0.08	1.01 ± 0.08

Table A.6.2 Allometric coefficients for the regression of lean weight on liveweight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.06 ± 0.04	1.04 ± 0.02	1.04 ± 0.02
Dorset Down	0.98 ± 0.08	1.01 ± 0.05	0.98 ± 0.05
Ile de France	0.85 ± 0.11	1.07 ± 0.06	1.13 ± 0.06
Oldenburg	1.28 ± 0.13	1.06 ± 0.07	1.06 ± 0.07
Oxford	1.17 ± 0.10	1.07 ± 0.06	1.07 ± 0.05
Suffolk	1.15 ± 0.08	1.08 ± 0.05	1.07 ± 0.05
Texel	1.05 ± 0.10	1.08 ± 0.05	1.08 ± 0.05
Southdown	0.92 ± 0.15	1.00 ± 0.09	0.98 ± 0.09
Cotswold	0.96 ± 0.17	0.87 ± 0.08	0.89 ± 0.08

Table A.6.3 Allometric coefficients for the regression of total fat on liveweight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.69 ± 0.10	1.64 ± 0.06	1.61 ± 0.06
Dorset Down	1.64 ± 0.22	1.59 ± 0.15	1.59 ± 0.15
Ile de France	2.07 ± 0.30	1.88 ± 0.20	1.86 ± 0.19
Oldenburg	1.76 ± 0.36	1.63 ± 0.20	1.65 ± 0.20
Oxford	1.70 ± 0.27	1.69 ± 0.17	1.68 ± 0.16
Suffolk	1.41 ± 0.23	1.59 ± 0.15	1.55 ± 0.15
Texel	1.80 ± 0.27	1.65 ± 0.16	1.51 ± 0.15
Southdown	1.75 ± 0.40	1.50 ± 0.27	1.48 ± 0.27
Cotswold	1.66 ± 0.46	1.60 ± 0.25	1.53 ± 0.24

Table A.6.4 Allometric coefficients for the regression of bone on liveweight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	0.73 ± 0.03	0.75 ± 0.02	0.76 ± 0.02
Dorset Down	0.77 ± 0.07	0.74 ± 0.05	0.75 ± 0.05
Ile de France	0.46 ± 0.10	0.74 ± 0.06	0.74 ± 0.06
Oldenburg	0.96 ± 0.12	0.73 ± 0.06	0.72 ± 0.06
Oxford	0.68 ± 0.09	0.75 ± 0.05	0.78 ± 0.05
Suffolk	0.80 ± 0.07	0.80 ± 0.05	0.81 ± 0.05
Texel	0.73 ± 0.09	0.78 ± 0.05	0.77 ± 0.05
Southdown	0.71 ± 0.13	0.79 ± 0.08	0.78 ± 0.08
Cotswold	0.71 ± 0.15	0.63 ± 0.08	0.65 ± 0.07

Table A.6.5 Allometric coefficients for the regression of subcutaneous fat on liveweight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	2.01 ± 0.16	1.82 ± 0.09	1.77 ± 0.09
Dorset Down	1.85 ± 0.35	1.69 ± 0.22	1.67 ± 0.21
Ile de France	2.20 ± 0.49	2.18 ± 0.29	2.17 ± 0.27
Oldenburg	2.47 ± 0.58	2.06 ± 0.29	2.05 ± 0.29
Oxford	2.16 ± 0.43	1.85 ± 0.24	1.80 ± 0.23
Suffolk	1.67 ± 0.37	1.71 ± 0.22	1.66 ± 0.21
Texel	2.22 ± 0.43	1.81 ± 0.23	1.66 ± 0.22
Southdown	1.85 ± 0.64	1.41 ± 0.39	1.43 ± 0.39
Cotswold	1.87 ± 0.74	1.83 ± 0.36	1.72 ± 0.35

Table A.6.6 Allometric coefficients for the regression of intermuscular fat on liveweight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.49 ± 0.09	1.46 ± 0.05	1.44 ± 0.05
Dorset Down	1.33 ± 0.19	1.35 ± 0.12	1.37 ± 0.12
Ile de France	1.80 ± 0.26	1.62 ± 0.16	1.59 ± 0.15
Oldenburg	1.69 ± 0.31	1.44 ± 0.17	1.45 ± 0.17
Oxford	1.38 ± 0.23	1.50 ± 0.14	1.53 ± 0.13
Suffolk	1.24 ± 0.20	1.40 ± 0.13	1.38 ± 0.12
Texel	1.77 ± 0.23	1.53 ± 0.13	1.42 ± 0.12
Southdown	1.53 ± 0.35	1.48 ± 0.22	1.47 ± 0.22
Cotswold	1.45 ± 0.40	1.39 ± 0.20	1.34 ± 0.20

Table A.6.7 Allometric coefficients for the regression of KKCF on liveweight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.65 ± 0.14	1.78 ± 0.09	1.75 ± 0.09
Dorset Down	1.92 ± 0.30	1.93 ± 0.21	1.97 ± 0.20
Ile de France	2.60 ± 0.41	1.85 ± 0.27	1.78 ± 0.25
Oldenburg	1.06 ± 0.49	1.51 ± 0.28	1.57 ± 0.28
Oxford	1.34 ± 0.36	1.89 ± 0.23	1.86 ± 0.22
Suffolk	1.31 ± 0.31	1.88 ± 0.21	1.88 ± 0.20
Texel	1.27 ± 0.36	1.58 ± 0.22	1.39 ± 0.21
Southdown	2.21 ± 0.54	2.01 ± 0.37	1.83 ± 0.36
Cotswold	1.98 ± 0.63	1.55 ± 0.34	1.55 ± 0.33

Table A.6.8 Allometric coefficients for the regression of total fat weight on lean weight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.45 ± 0.09	1.40 ± 0.06	1.35 ± 0.06
Dorset Down	1.54 ± 0.21	1.43 ± 0.14	1.41 ± 0.14
Ile de France	1.96 ± 0.32	1.53 ± 0.18	1.45 ± 0.16
Oldenburg	1.42 ± 0.27	1.31 ± 0.18	1.32 ± 0.19
Oxford	1.41 ± 0.22	1.47 ± 0.15	1.40 ± 0.14
Suffolk	1.11 ± 0.19	1.34 ± 0.14	1.33 ± 0.14
Texel	1.55 ± 0.24	1.38 ± 0.14	1.25 ± 0.14
Southdown	1.88 ± 0.44	1.25 ± 0.26	1.20 ± 0.27
Cotswold	1.21 ± 0.44	1.52 ± 0.27	1.44 ± 0.26

Table A.6.9 Allometric coefficients for the regression of subcutaneous fat weight on lean weight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.78 ± 0.14	1.59 ± 0.08	1.53 ± 0.08
Dorset Down	1.82 ± 0.32	1.58 ± 0.20	1.55 ± 0.20
Ile de France	2.11 ± 0.49	1.80 ± 0.25	1.72 ± 0.23
Oldenburg	2.01 ± 0.42	1.68 ± 0.25	1.70 ± 0.26
Oxford	1.81 ± 0.34	1.67 ± 0.21	1.55 ± 0.20
Suffolk	1.34 ± 0.29	1.45 ± 0.20	1.43 ± 0.19
Texel	2.00 ± 0.37	1.54 ± 0.20	1.40 ± 0.19
Southdown	2.01 ± 0.67	1.18 ± 0.37	1.13 ± 0.37
Cotswold	1.40 ± 0.68	1.80 ± 0.37	1.68 ± 0.35

Table A.6.10 Allometric coefficients for the regression of intermuscular fat weight on lean weight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.24 ± 0.08	1.21 ± 0.05	1.18 ± 0.05
Dorset Down	1.22 ± 0.19	1.17 ± 0.12	1.16 ± 0.12
Ile de France	1.72 ± 0.29	1.31 ± 0.16	1.25 ± 0.14
Oldenburg	1.31 ± 0.25	1.14 ± 0.16	1.15 ± 0.16
Oxford	1.10 ± 0.20	1.23 ± 0.13	1.22 ± 0.12
Suffolk	0.96 ± 0.17	1.18 ± 0.12	1.17 ± 0.12
Texel	1.45 ± 0.22	1.24 ± 0.12	1.15 ± 0.12
Southdown	1.63 ± 0.40	1.21 ± 0.23	1.18 ± 0.23
Cotswold	1.06 ± 0.40	1.26 ± 0.23	1.21 ± 0.22

Table A.6.11 Allometric coefficients for the regression of KKCF on lean weight

	Coefficient estimated from model		
	4	3	1
Pooled estimate	1.31 ± 0.13	1.50 ± 0.08	1.44 ± 0.08
Dorset Down	1.70 ± 0.30	1.70 ± 0.19	1.69 ± 0.19
Ile de France	2.23 ± 0.45	1.36 ± 0.24	1.26 ± 0.22
Oldenburg	0.71 ± 0.39	1.07 ± 0.25	1.10 ± 0.25
Oxford	1.22 ± 0.32	1.70 ± 0.20	1.61 ± 0.20
Suffolk	0.99 ± 0.27	1.62 ± 0.19	1.62 ± 0.18
Texel	1.10 ± 0.34	1.33 ± 0.19	1.18 ± 0.19
Southdown	2.36 ± 0.63	1.69 ± 0.36	1.57 ± 0.36
Cotswold	1.25 ± 0.63	1.44 ± 0.36	1.46 ± 0.34

APPENDIX 7

ALLOMETRIC COEFFICIENTS FOR THE LINEAR REGRESSIONS OF $\log_{10}$ LEAN ON $\log_{10}$ BONE

Table A.7.1 Allometric coefficients for the linear regression of $\log_{10}$ lean on $\log_{10}$ bone

	b ± s.e.		b ± s.e.
Pooled regression	1.20 ± 0.06	Dam breed	
		Tex-Old	1.25 ± 0.19
Sire breed		Dam Line	1.22 ± 0.08
Dorset Down	1.11 ± 0.12	Greyface	1.18 ± 0.09
Ile de France	1.27 ± 0.29	Blackface	0.89 ± 0.37
Oldenburg	1.00 ± 0.17		
Oxford	1.41 ± 0.16		
Suffolk	1.27 ± 0.12	Ewe age	
Texel	1.29 ± 0.16	Two	1.22 ± 0.08
Southdown	1.07 ± 0.23	Three	1.18 ± 0.08
Cotswold	1.19 ± 0.27		
Year		Sex	
1976	1.27 ± 0.07	Female	1.11 ± 0.08
1977	1.04 ± 0.10	Wether	1.29 ± 0.08

PUBLICATIONS

Some results from this Thesis have been published as follows:

WOLF, B.T., SMITH, C. and SALES, D.I. (1980)
Growth and carcass composition in the crossbred progeny of six terminal sire breeds of sheep. Anim. Prod. 31 : 307-313.

WOLF, B.T., SMITH, C., KING, J.W.B. and NICHOLSON, D. (1981)
Genetic parameters of growth and carcass composition in crossbred lambs. Anim. Prod. 32 : 1-7.

WOLF, B.T. (1982)
An analysis of the variation in the lean tissue distribution of sheep. Anim. Prod. (in press).

Anim. Prod. 1980, **31**: 307–313

0003-3561/80/98730307 $02·00

GROWTH AND CARCASS COMPOSITION IN THE CROSSBRED PROGENY OF SIX TERMINAL SIRE BREEDS OF SHEEP

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ABSTRACT

Records were available for the progeny of Dorset Down, Oxford, Suffolk, Ile-de-France, Oldenburg and Texel sires out of Border Leicester × Blackface and Animal Breeding Research Organisation Dam Line × Blackface ewes. The data analysed were: (a) growth traits to 12 weeks for 2585 lambs, the progeny of 102 sires; (b) growth traits for slaughter at fixed weights of 35 kg and 40 kg for 1884 lambs (79 sires); and (c) half carcass dissection traits for 956 lambs (65 sires).

Oxford and Suffolk cross lambs were heaviest at all ages and thus youngest at slaughter. Texel cross lambs grew slowly to 12 weeks but were not significantly older than Dorset Down, Ile-de-France and Oldenburg cross lambs at slaughter. The Texel cross produced the leanest carcass with a high lean/bone ratio and eye-muscle area. Dorset Down and Ile-de-France cross lambs were fattest at slaughter but had high values for lean/bone ratio and eye-muscle area. Interactions between breed of sire and slaughter weight were non-significant for all traits ($P > 0{\cdot}05$).

Breed differences in carcass composition were also compared statistically as if at a constant percentage of subcutaneous fat. The differences were not so great as at constant live weight but the Texel cross would have had the leanest carcass. Side weights would be heaviest in the Texel and lowest in the Dorset Down and Ile-de-France. Oxford, Suffolk and Dorset Down cross lambs would be youngest at slaughter and Texel and Oldenburg crosses oldest.

INTRODUCTION

LAMB production on lowland farms in the United Kingdom is based upon the use of rams of the terminal sire breeds mated to crossbred ewes. The Down breeds, and the Suffolk in particular, make an important contribution to the production of meat lambs (Meat and Livestock Commission, 1972). However little is known about the comparative performance of the many breeds available since they have rarely been compared in the same flock. In this paper three British and three imported breeds are compared as sires of crossbred meat lambs.

MATERIAL AND METHODS

The data analysed were collected from lambs reared at the Animal Breeding Research Organisation's lowland experimental farm, Cold Norton, Staffordshire, between 1972 and 1976. Two crossbred ewe types, the progeny of ABRO Dam Line and Border Leicester sires mated to Scottish Blackface dams (ewes), were produced on an Ayrshire hill farm and introduced to the experiment annually in groups of approximately 100 young female sheep (ewe lambs) per breed type. The ewe lambs were allowed to mate and remained in the flock until the end of their 3rd year. The Dorset Down, Oxford Down, Suffolk, Ile-de-France, Oldenburg and Texel breeds were represented throughout the experiment, but different sires were used in each year. Two sires of each breed produced progeny in 1972, three per breed in 1973 and four per breed in subsequent years.

Approximately 10 ewes per ewe type were assigned at random to each sire (ram) for a 4-week mating period beginning in mid-October each year. Nutrition during the first 15 weeks of pregnancy was controlled, by the supplementary feeding of hay if necessary, to maintain ewe body condition. During the final 6 weeks of pregnancy the flock was managed in three groups according to date of mating. Supplementary concentrate feeding was introduced at 0·1 kg per head per day when the first ewe in each group was within 6 weeks of its estimated lambing date, and rose to 0·3 kg per head per day 3 weeks before lambing

and to 0·7 kg per head per day in the final week.

Immediately after parturition mis-mothering was prevented by individually penning ewes and their litters until the lambs were tagged and weighed. Birth weight, to the nearest 0·1 kg, ewe and lamb identities, and lamb sex and litter type were recorded when the birthcoat had dried. Any lamb born outside the range of 145 ± 4 days of its dam's recorded mating date was considered non-pedigree and was rejected in the analysis. Castration and docking took place within 24 h of birth. Lambs were weighed to the nearest 0·5 kg at 4, 8, 12 and 16 weeks of age. In 1972/73 weaning took place at 12 weeks but in subsequent years the lambs remained with their dams until 16 weeks of age. The weaned lambs were grazed on grass-clover mixtures and were dosed against intestinal parasites at 4-week intervals. Lambs were randomly assigned to slaughter at either 35 kg or 40 kg live weight. Slaughter took place each week at a local abattoir. MLC Sheep Carcass Classification information and cold carcass weights (to nearest 0·5 kg) were recorded for all lambs. In 1973–75 samples of carcasses were randomly assigned within breed of sire for dissection. The dissection procedures used have been outlined by Cuthbertson, Harrington and Smith (1972). The kidney knob and channel fat (KKCF) was removed and the left side of the carcass was cut into eight standard joints using anatomical reference points. Individual joints were then dissected into subcutaneous fat, intermuscular fat, lean, bone and trimmings. Subcutaneous fat depth (backfat depth) was measured on the cut surface at the twelfth rib at a point 4 cm from the midline: a photograph of this surface was used to give a measurement of *m. longissimus* area (reported in this analysis as eye-muscle area) using a d-mac pencil follower.

Statistical procedures

The data were analysed by least squares using the COMPREG statistical package (Russell, 1973). In order to construct the analysis of variance tables required, four statistical models were used, as shown in Table 1. Factors with large numbers of classes, for which fitted constants were not required, were fitted by absorption, that is by absorbing the least squares equations for these factors into the other equations. Some of the necessary mean squares for hypothesis testing were obtained as the difference of the residual sums of squares in the different models. For example, to test for breed of sire effects, the difference in the residual sums of squares for models 1 and 2 gave the mean square for sires within breed of sire and year, and similarly for other hypothesis tests. Tests were made for sire by breed of dam interactions but they did not approach significance for any of the traits ($P > 0{\cdot}05$) and so they were omitted from the models. Fixed effects were fitted for sex, ewe age, rearing type (litter size) and slaughter group, and linear regressions were fitted on birth date and deviation in age due to a weekly weigh day. Differences between specific class effects (such as differences between two sire breeds) were tested using Duncan's multiple range test as modified by Kramer (1957).

TABLE 1

Basic statistical models used to construct the analysis of variance table

	Model number			
	1	2	3	4
Breed of sire	F†	A‡	A	A
Breed of dam	F	F	A	A
Year	F	A	A	A
Breed of sire × breed of dam	F	F	A	A
Breed of sire × year	F	A	A	A
Breed of dam × year	F	F	A	A
Sires/(breed of sire, year)	—	A	A	A
Breed of dam × sire/ (breed of sire, year)	—	—	A	A
Dams/breed of dam/sires/ (breed of sire, year)	—	—	—	A

†F = effect fitted directly.
‡A = effect fitted by absorption.

RESULTS

Unadjusted means and standard deviations for all traits are given in Table 2. Comparing the latter with the residual standard deviations for model 1 showed that the breeds and fixed effects accounted for 40 to 60% of the total variation in weight for age and growth rate, and from 20 to 40% of that for the carcass traits.

Breed of sire explained a significant amount of variation in all growth and slaughter traits ($P < 0{\cdot}05$) except birth weight (Table 3). By 12 weeks of age the Oxford and Suffolk cross lambs were heavier and Texel crosses were lighter than

lambs of the other three breed crosses. This ranking of breeds was relevant for average daily gain from birth to 12 weeks, but consideration of pre-weaining daily gains in three 4-week periods showed consistently high rates of gain for the Oxford cross whilst the differences between the Suffolk and Texel crosses and the other breeds were not well established until the 4- to 8-week period. The growth rate of the Texel cross between 8 and 12 weeks of age was particularly low.

Although post-weaning growth rate was not analysed as a separate trait, the lower age at slaughter of the Oxford and Suffolk crosses indicates that they maintained their growth advantage during this period. The Texel cross appeared to have compensated for its early growth rate and did not differ significantly from the other breeds in slaughter age.

Although significant differences in killing-out percentage were found (Table 3), when the smaller dissected sample was analysed only the Oldenburg cross differed significantly from the other breeds ($P<0.05$) (Table 4). Breed of sire effects were significant for all other carcass traits. The Oldenburg, Oxford and Suffolk cross lambs did not differ significantly from one another for percentage lean and bone in the carcass, lean/bone and lean/fat ratios, backfat depth or eye-muscle area. The Suffolk had 1·7% more fat in the carcass than the Oldenburg but neither differed significantly from the Oxford cross. Dorset Down cross lambs yielded carcasses containing a higher percentage fat, higher lean to bone ratio but lower lean to fat ratio than the three breeds described above. The carcass of the Ile-de-France cross lamb was intermediate between the Dorset Down and Suffolk for percentage lean and fat but did not differ significantly from the Dorset

TABLE 2

Means and standard deviations calculated from unadjusted data and pooled within breed residual standard deviations after adjustment for fixed effects

Trait	Mean	s.d.	Residual s.d.†
Weight (kg)			
At birth	4·2	1·02	0·68
4 weeks	12·8	2·99	1·91
8 weeks	21·2	4·23	2·82
12 weeks	28·6	5·12	3·58
Average daily gains (g/day)			
Birth–4 weeks	280	71	52
4–8 weeks	297	72	59
8–12 weeks	268	69	63
Slaughter age (days)	155	55	41
Killing-out %	43·7	3·61	2·96
Carcass weight/day of age (g/day)	121	43	29
Side weight (kg)	8·24	1·15	0·83
Tissue in side (%)			
Lean	55·7	4·37	3·30
Bone	16·1	2·01	1·65
Fat (including KKCF)	26·7	5·65	4·33
Lean weight/day of age (g/day)	65·5	21·31	16·75
Lean/bone ratio	3·48	0·39	0·32
Lean/fat ratio	2·22	0·69	0·54
Subcutaneous/intermuscular fat ratio	1·13	0·23	0·21
Backfat depth (mm)	4·03	2·06	1·84
Eye-muscle area (cm^2)	10·8	1·69	1·58

†Residual standard deviation from model 1.

TABLE 3

Least squares means† and fitted constants for growth and slaughter traits

		Birth weight	12-week weight	Average daily gains (g/day)				Slaughter age	Killing-out %	Carcass weight day
	Number	(kg)	(kg)	0–4 weeks	4–8 weeks	8–12 weeks	Number	(days)		(g/day)
Fitted mean†	2585	4·29	29·8†	281	315	285	1884	145	43·7	126
Sire breed		NS	***	*	**	***		**	***	**
Dorset Down	423	−0·05	−0·26^{a}‡	−1·89^{ab}	2·04^{bc}	−7·18^{a}	317	5·62	0·71^{a}	−2·95
Ile-de-France	443	−0·12	−0·56^{ab}	−6·83^{ab}	−5·46^{ab}	−2·45^{ab}	323	7·54	0·57^{a}	−2·97
Oldenburg	403	0·05	−0·12^{a}	−3·43^{ab}	−6·83^{ab}	4·55^{bc}	280	5·77	−1·79^{b}	−7·80
Oxford	424	0·11	1·29^{c}	10·73^{c}	13·40^{d}	16·77^{d}	299	−15·60^{a}	−0·10^{c}	11·02^{a}
Suffolk	447	0·01	0·75^{c}	3·49^{bc}	11·47^{cd}	11·21^{cd}	322	−8·11^{a}	−0·14^{c}	5·69^{a}
Texel	445	0·00	−1·11^{b}	−2·07^{ab}	−14·62^{a}	−22·90^{e}	343	4·78	0·75^{a}	−2·98
Approximate s.e.		0·04	0·19	2·74	3·07	3·32		2·52	0·19	1·81

†Standardized to twin, castrated male lambs reared by 2-year-old ewes.
‡Values with different superscripts are significantly different ($P<0.05$).

TABLE 4

Least squares means† and fitted constants for carcass traits at constant live weight

	Number dissected	Side weight (kg)	% lean	% bone	% fat	Lean/bone ratio	Lean/fat ratio	SF/IMF‡ ratio	Backfat depth (mm)	Eye-muscle area (cm^2)	Lean weight/day (g/day)
Fitted mean	956	8·01	56·84	16·83	24·75	3·41	2·41	1·08	3·52	10·70	64·62
Sire breed		*	***	***	***	***	***	*	**	**	**
Dorset Down	154	0·08	−2·15[a]§	−0·93[a]	3·13[a]	0·06[a]	−0·34[a]	0·05[a]	0·67[a]	0·15[ab]	−4·50[a]
Ile-de-France	163	0·06	−1·06[ab]	−0·47[ab]	1·56[b]	0·03[a]	−0·19[ab]	0·00[abc]	0·42[ab]	0·23[ab]	−2·06[a]
Oldenburg	138	−0·29[a]	0·64[c]	0·77[c]	−1·52[c]	−0·12[b]	0·13[bc]	−0·01[bc]	−0·41[cd]	−0·55[c]	−3·83[a]
Oxford	156	0·03	−0·56[bc]	0·65[c]	−0·11[cd]	−0·17[b]	−0·04[bc]	0·02[ab]	0·19[abc]	−0·24[bc]	5·63[b]
Suffolk	158	0·01	−0·55[bc]	0·34[c]	0·20[bd]	−0·11[b]	−0·04[bc]	−0·05[c]	−0·14[bcd]	−0·14[bc]	2·82[bc]
Texel	187	0·10	3·68[d]	−0·35[b]	−3·26[c]	0·31[c]	0·48[d]	−0·00[abc]	−0·73[d]	0·56[a]	1·94[c]
Approximate s.e.		0·06	0·25	0·12	0·32	0·02	0·04	0·02	0·15	0·13	1·24
Slaughter group											
One (35 kg)	451	−0·66	1·01	0·60	−1·67	−0·07	0·19	−0·05	−0·56	−1·73	4·53
s.e.		0·04	0·16	0·08	0·20	0·07	0·02	0·01	0·09	0·81	0·67

In this and Table 5,
†Standardized to twin, castrated male lambs reared by 2-year-old ewes.
‡Subcutaneous fat/intermuscular fat ratio.
§Values with different superscripts are significantly different ($P<0·05$).

Down cross for lean to bone ratio. The proportion of lean in the carcass of the Texel cross lamb was 3·7 percentage points above the mean for all breeds and this was associated with a low level of fat, a moderately low proportion of bone and thus high lean/bone and lean/fat ratios.

Lean tissue growth rate, as estimated by the weight of lean deposited per day of age, was highest in the Oxford and Suffolk crosses, but despite its higher slaughter age the Texel cross did not differ significantly from the Suffolk cross for this trait. The three other breeds all had significantly lower values than the Texel.

Although the experimental design provided for slaughter weights of 35 kg and 40 kg the mean live weights at slaughter were 35·7 kg and 41·62 kg respectively. Lambs in the lighter group were on average 37 days younger at slaughter than animals in the heavier group. Their average side weight was 1·12 kg lower and contained 2·02% more lean and 3·34% less fat. The breed of sire by slaughter group interaction was non-significant for all traits.

The breed of sire by year interaction was significant for 12-week weight, average daily gain (ADG) from 4 to 8 weeks and ADG from 8 to 12 weeks ($P<0·05$). These interactions were largely due to relatively high performance by the Texel and Ile-de-France breeds in 1974 and by the Oldenburg in 1976. The breed of sire by breed of dam interaction was significant for slaughter age only ($P<0·05$). Lambs sired by Oldenburg rams were older at slaughter when reared by Border Leicester cross ewes, in contrast to the Ile-de-France and Suffolk lambs which were not affected by the breed of dam, and the Texel, Oxford and Dorset Down cross lambs which were younger at slaughter when reared by Border Leicester cross ewes.

Another criterion, apart from weight, in sale of lambs for slaughter is their level of subcutaneous fat. So the sire breed comparisons were also made after statistically adjusting the data to an equal percentage subcutaneous fat in the side, using the pooled within-breed linear regression (Table 5). There was little change in the adjusted means for the slaughter age of the Oxford and Suffolk crosses but the means for the Dorset Down would be considerably lower, and those for Oldenburg and Texel would be larger, than at a constant live-weight. Breed differences for side weight appeared in this analysis, indicating that

TABLE 5

Least squares means† and fitted constants for carcass traits after adjustment to constant percentage of subcutaneous fat (11·3%) in the side

	Slaughter age (days)	Slaughter weight (kg)	Side weight (kg)	% lean	% bone	% fat	Lean/ bone ratio	Lean/ fat ratio	SF/ IMF‡ ratio	Lean weight/ day (g/day)
Fitted mean†	152·63	39·62	7·54	55·67	16·34	26·44	3·44	2·23	1·15	57·57
Sire breed	**	**	***	***	***	**	***	**	***	**
Dorset Down	−4·53^{ab}§	−1·00^{a}	−0·29^{a}	−0·26^{a}	−0·12^{a}	0·37^{a}	0·01^{a}	−0·02^{ab}	−0·04^{a}	−2·57^{ab}
Ile-de-France	0·73^{bc}	−0·83^{a}	−0·14^{ab}	−0·25^{a}	−0·11^{a}	0·36^{a}	0·00^{a}	−0·06^{a}	−0·04^{a}	−0·87^{ab}
Oldenburg	10·01^{cd}	0·61^{b}	−0·12^{ab}	−0·20^{a}	0·41^{b}	−0·30^{b}	−0·10^{a}	−0·01^{ab}	0·03^{a}	−4·72^{a}
Oxford	−13·92^{a}	0·15^{b}	0·02^{b}	−0·46^{a}	0·68^{b}	−0·24^{b}	−0·17^{a}	−0·02^{ab}	0·02^{a}	5·62^{c}
Suffolk	−5·70^{ab}	0·26^{b}	0·05^{b}	−0·68^{a}	0·28^{b}	0·40^{a}	−0·10^{a}	−0·07^{a}	−0·04^{a}	2·48^{bc}
Texel	13·41^{d}	0·82^{b}	0·48^{c}	1·84^{b}	−1·13^{c}	−0·60^{b}	0·36^{b}	0·18^{b}	0·08^{b}	0·07^{ab}
Approximate s.e.	3·33	0·26	0·06	0·13	0·09	0·13	0·02	0·02	0·01	1·29
Regression on % subcutaneous fat	7·30	0·82	0·27	−1·10	−0·45	1·57	0·03	−0·18	0·05	−1·67
s.e.	0·88	0·08	0·02	0·04	0·03	0·04	0·01	0·01	0·003	0·30

the Dorset Down would be some 0·77 kg lighter than the Texel. Correspondingly, differences in percentage lean, fat and bone in the side would not be so large as at equal live weight. However, the Texel would still produce a high percentage of lean in the side with high ratios for lean/bone and lean/fat, perhaps indicating differences in fat distribution between the breeds. Breed of sire × year and breed of sire × breed of dam interactions were non-significant for all traits considered, when subcutaneous fat percentage was held constant.

DISCUSSION

The lack of significant interaction between sire breed and dam breed is consistent with the conclusion of Vesely, Kozub and Peters (1977), that specific combining ability is of little importance in the design of sheep breeding plans. The absence of significant interactions between sires and breed of dam suggests that selection within a terminal sire breed may be made for growth and carcass composition without reference to ewe breed used in the production of the crossbred lamb. This result agrees with Bowman and Broadbent (1966) but might have to be modified if ewe breeds differed widely in mature size.

The interactions of breed of sire and year for growth traits are disconcerting. However, different sets of sires were used in each year, so sire sampling variation may have contributed to the interaction. Also, when years were grouped by level of performance the breeds did not rank consistently between years within the same group. Nevertheless, it might be worthwhile to check that breeds do not rank differently in different years and environments, that is to check on the generality of the sire breed rankings.

Although the breed of sire effect for birth weight was not significant, the ranking of the breeds for this trait was consistent with that of More O'Ferrall and Timon (1977a). The Suffolk and Texel comparisons for live-weight growth and slaughter age were also similar. However, they did not find consistently higher growth rates in the Oxford than in the Suffolk. They also reported a much higher slaughter age in the Dorset Down and Ile-de-France cross lambs relative to the Texel cross. These differences between the two trials may be due to sampling as the Oxford, Dorset Down and Ile-de-France breeds were each represented by only four sires in the Irish experiment. A further cause of the differences between the two trials, particularly in slaughter age differences for the Texel *v.* the Dorset Down and Ile-de-France, could be variation in nutritional conditions. Osikowski and Borys (1976) in a crossing experiment with Merino sheep found that lambs sired by rams of Ile-de-France and Texel and reared under semi-intensive conditions did not differ significantly in slaughter age at 46 kg live weight.

The high values for percentage lean in the

carcass, lean/bone ratio and eye-muscle area of the Texel are in agreement with investigations at similar slaughter weights (Flamant and Perret, 1976; More O'Ferrall and Timon, 1977b; Osikowski and Borys, 1976). The Ile-de-France, Oxford and Suffolk lambs did not differ greatly for carcass composition, and the carcasses of the Dorset Down cross lambs were fattest and had high lean/bone ratio and eye-muscle areas (More O'Ferrall and Timon, 1977b). The absence of a significant sire breed by slaughter group interaction was also in agreement with the results of More O'Ferrall and Timon (1977b), but highly significant interactions of this type reported by Vesely and Peters (1972) suggest that studies over a wide range of carcass weights would produce more information about optimum slaughter weights for different breeds.

Breed utilization is dependent upon considerations of suitability for production systems and the market acceptability of the carcass. In the United Kingdom, lowland lamb production systems are related to market prices which themselves are a function of supply and demand. High prices per unit carcass weight are achieved in early spring, late autumn and winter, with the largest supply and thus lowest prices occurring in summer and early autumn. Production systems are of three types: (1) early lamb production to achieve high market prices; (2) production off grass; and (3) production off grass and forage crops with the sale of heavy lambs during a period of increasing market prices. At any given weight the market requirement is for maximum lean, minimum bone and optimum fat, with preference for a high ratio of subcutaneous to intramuscular fat, since the latter cannot be trimmed readily for sale. Although the lambs in this experiment were slaughtered according to constant live weight criteria, the means and standard deviations for carcass traits were in good agreement with these for commercial samples of lambs (Kempster and Cuthbertson, 1977). However, the interpretation and application of the results of this experiment are only valid for a limited range of environments and slaughter weights. The Oxford and Suffolk appear to be most suitable for lamb production systems which require rapid growth to live weights up to 40 kg. Adjustment of the data to a constant percentage subcutaneous fat suggests that where early achievement of a given level of carcass finish and light carcass weights are required the Dorset Down may be the most suitable breed choice. The slow growth, but lean carcass of the Texel cross lamb had led many authors to advocate the use of this breed for heavy lamb production (e.g. More O'Ferrall and Timon, 1977b). However, breed comparisons at constant percentage of subcutaneous fat suggests that the increase in slaughter weight which can be achieved may not be large. Further experiments with lambs reared on different planes of nutrition and slaughtered at heavier weights than 40 kg are required before this problem can be solved.

Of the three imported breeds examined in this experiment the Oldenburg and Ile-de-France apparently have little to recommend their continued substitution for indigenous breeds. Substitution of the Suffolk by the Texel may be desirable in certain production systems and markets, but such substitution may not be economically viable unless the disadvantage of a higher slaughter age is offset by the payment of suitable premiums for the extra lean produced.

Finally, the relationship between the mature size of the terminal sire breed and growth rate is of biological interest. Estimates of live weight at maturity (J. L. Read, personal communication) are Dorset Down (81 kg), Oldenburg (72 kg), Oxford (98 kg), Suffolk (92 kg) and Texel (90 kg). The ranking of the Oxford, Suffolk, and Dorset Down for live weight and lean growth rates to a fixed live weight was consistent with these estimates of their mature size. However, the Oldenburg and the Texel crosses seem to be anomalous. Values for live weight and lean growth rate were lower than expected in the Oldenburg cross. In the Texel, live weight growth to a fixed live weight was lower than expected from estimates of the mature size, whilst lean growth rates were higher. At a constant percentage for subcutaneous fat the ranking for lean growth rate was consistent with estimates of their mature size for all breeds, except for the Oldenburg.

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GENETIC PARAMETERS OF GROWTH AND CARCASS COMPOSITION IN CROSSBRED LAMBS

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ABSTRACT

Data were available on crossbred meat lambs for 10 live-weight and growth traits (2585 lambs), 5 carcass traits (1884 lambs) and 10 dissection traits (944 lambs). These were the progeny born on an experimental farm over 5 years, from 102, 79 and 65 sires respectively for the three groups of traits. Genetic parameters were estimated from the sire components in a nested analysis of variance within breed of sire and year subclass, adjusting for sex, dam age, rearing type and other factors.

The heritabilities of the live-weight and growth traits were all low, the highest being average daily gain to slaughter (0·10, s.e. 0·06), and none was statistically significant. The heritabilities of the traits of carcass composition were much higher: percentage lean (0·41, s.e. 0·13), percentage fat (0·37, s.e. 0·13) and percentage bone (0·16, s.e. 0·10). Intermediate values were found for most other traits: killing-out percentage (0·16, s.e. 0·07), fat depth (0·21, s.e. 0·11), eye-muscle area (0·14, s.e. 0·10) and lean/bone ratio (0·13, s.e. 0·09).

Phenotypic and genetic correlations among the traits were also estimated. No major incompatibilities were found among the traits. The results are discussed in relation to the genetic improvement of lean meat production in sheep.

INTRODUCTION

The design of genetic improvement schemes for any species depends on the heritability of traits of economic importance, and on the genetic relationships among traits. A number of authors have reported heritability estimates for the live-weight growth of lambs under British production systems. Since these tend to be low some effort has been directed towards the development of suitable performance test regimes, e.g. Owen, Brook, Read, Steane and Hill (1978). Heritability estimates for carcass traits such as killing-out percentage, backfat depth and eye-muscle area have been reported by a number of authors but the genetic parameters of lamb carcass composition are poorly documented. The majority of published results are of limited value due to the use of small samples or partial dissection techniques.

This paper reports heritability estimates for live weight, growth and carcass composition for crossbred meat lambs. Genetic correlations between carcass traits, and between growth and carcass composition at a fixed live weight are presented and the results are discussed in relation to market requirements for lean meat.

MATERIAL AND METHODS

A detailed description of the experimental design and the management of the flock was given by Wolf, Smith and Sales (1980) and only information pertinent to this study will be given here. The data were collected from crossbred meat lambs reared at the Animal Breeding Research Organisation's lowland experimental farm, Cold Norton, Staffordshire. Six terminal ram breeds, Dorset Down, Ile-de-France, Oldenburg, Oxford, Suffolk and Texel, were used. Different sires were used in each year of the experiment—two per breed in 1972, three per breed in 1973 and four per breed in subsequent years. Sires of the Oxford breed were selected at random from the ABRO Oxford control flock whilst sires of the other breeds were, as far as possible, a random sample of those available in pedigree flocks. The Texel stock was of Dutch origin imported to Great Britain via Eire.

Two types of crossbred ewe, Border Leicester × Blackface (Greyface) and ABRO Dam Line × Blackface, were produced on an Ayrshire hill farm and were taken to the experimental flock at 5 months of age. A more complete description of the genetic composition of the female stock has

been given by Smith, King, Nicholson, Wolf and Bampton (1979).

Approximately 10 ewes of each crossbred type were randomly allocated to each sire for mating in mid-October and lambs were born in a 4-week period during March and April in each year. Pedigree information, sex, birth-type and weight (to the nearest 0·1 kg) were recorded at birth. Any lamb born outside the range 145 ± 4 days of its dam's observed mating date was classified as non-pedigree and excluded from the analysis. Live weights were recorded to the nearest 0·5 kg at 4, 8 and 12 weeks of age. The lambs were allocated at random to slaughter at a fixed live weight of either 35 or 40 kg. Meat and Livestock Commission Sheep Carcass Classification information and hot carcass weights were recorded at slaughter. Between 1973 and 1975 samples of carcasses were randomly assigned for MLC dissection of the left side into lean, bone and fat.

Statistical methods

A nested analysis of variance between sires within breed of sire by year subclass, between dams within sire and within dams was performed using a standard program package (Thompson, 1968). This program allows covariate adjustment of discrete classes (e.g. rearing types) by fitting of 'dummy' variables (0 if class is absent, 1 if present) for each individual. Adjustments were made for continuous variates by regression. The components of variance and covariance were then estimated from the analysis of variance by equating the mean squares to their expectations under the assumption that all elements, except the mean, are random variables. These components were then used in the calculation of heritability and correlation coefficients.

The data were analysed in three sets. The first contained records for 2585 lambs, the progeny of 102 sires, born between 1972 and 1976 and having complete records from birth to 12 weeks. The second data set contained records for 1884 lambs, the progeny of 79 sires, born between 1972 and 1975 and having complete records from birth to slaughter. The third set contained records for 944 lambs, the progeny of 65 sires, born between 1973 and 1975 and having complete half carcass dissection records. The degrees of freedom and coefficients of the components of variance (σ_S^2, σ_D^2 and σ_R^2) in the expectation of the mean squares, are shown in Table 1.

Adjustments were made for breed of dam, ewe age (1, 2 and 3 years), lamb sex (female, castrate) and date of birth (linear regression) in the analysis of each set of data. Breed of dam was also included as a covariate. This should not bias the parameter estimates as the sire × breed of dam interaction was previously shown to be non-significant for all traits considered (Wolf *et al.*, 1980). Adjustment was also made for birth-rearing type (single-single, twin-twin, twin-single, triplet-triplet, triplet-twin, triplet-single, other) and age deviation (plus 0 to 6 days) from stated age at weight measurement in the live weight

TABLE 1

Degrees of freedom and coefficients of expectation of the mean squares

	Data set	d.f.	Coefficients of e.m.s.		
			Residual	Dam	Sire
			σ_R^2	σ_D^2	σ_S^2
Sires/breed of sire and year	Growth to 12 weeks	72	1	1·85	25·18
	Growth to slaughter	55	1	1·82	23·59
	Carcass dissection	47	1	1·65	14·10
Dams/sires	Growth to 12 weeks	1420	1	1·67	
	Growth to slaughter	1047	1	1·63	
	Carcass dissection	558	1	1·48	
Lambs/dams	Growth to 12 weeks	1045	1		
	Growth to slaughter	739	1		
	Carcass dissection	313	1		

data sets, and for rearing type (single, twin, triplet) and slaughter weight by linear regression in the carcass data set (adjustment was also made for slaughter weight in the analysis of slaughter age, average daily gain from birth to slaughter and killing-out percentage).

Heritabilities were estimated by $4\sigma_S^2/\sigma_T^2$, where $\sigma_T^2=\sigma_S^2+\sigma_D^2+\sigma_R^2$ and litter variance was estimated as $(\sigma_D^2-\sigma_S^2)/\sigma_T^2$. Correlations were estimated by $CV_T(X, Y)/\sqrt{(\sigma_{TX}^2\sigma_{TY}^2)}$ and genetic correlations by $CV_S(X, Y)/\sqrt{(\sigma_{SX}^2\sigma_{SY}^2)}$. The standard errors of the estimates were calculated using the general formulae of Becker (1975).

RESULTS

Least squares means, fitted values and the residual standard deviations for all traits were given in a previous paper (Wolf *et al.*, 1980). The residual standard deviations estimate the phenotypic standard deviations of the traits considered.

Heritabilities

Estimates of the heritability and litter variance for live-weight growth traits and killing-out percentage are shown in Table 2. All heritability values for traits measured prior to 12 weeks of age were non-significant and below 0·10. The estimate for average daily gain (ADG) from birth to slaughter approached significance (0·10, s.e. 0·06). Killing-out percentage was a moderately heritable trait (0·16, s.e. 0·07). Estimates of the litter variance were much higher than the heritability estimates but tended to be lower for ADG birth to slaughter, slaughter age and killing-out percentage.

Carcass dissection traits were more highly heritable than growth traits and estimates of the litter variance were lower (Table 3). Heritability estimates for percentage lean, lean/fat ratio and percentage of each fat depot in the carcass were particularly high, but estimates for lean/bone ratio and fat distribution (subcutaneous/intermuscular fat ratio) were not significantly different from zero. Heritability values for subcutaneous fat depth, eye-muscle area and visual carcass assessment scores also tended to be lower than those for gross carcass composition. The heritability estimate for lean weight/day of age (0·23, s.e. 0·11) did not differ significantly from the heritability for ADG birth to slaughter (0·24, s.e. 0·11) estimated from this data set.

TABLE 2

Estimates of the heritability and litter variance of growth traits

	Heritability	s.e.	Litter variance†	s.e.
Birth weight	0·06	0·05	0·39	0·03
4-week weight	−0·02	0·03	0·39	0·03
8-week weight	0·05	0·04	0·38	0·03
12-week weight	0·04	0·04	0·37	0·03
Average daily gains				
Birth–12 weeks	0·04	0·04	0·38	0·03
Birth–4 weeks	−0·00	0·04	0·42	0·03
4–8 weeks	0·04	0·04	0·37	0·03
8–12 weeks	−0·03	0·03	0·41	0·03
Birth–slaughter	0·10	0·06	0·33	0·04
Slaughter age	0·07	0·05	0·21	0·04
Killing-out %	0·16	0·07	0·25	0·04

†Estimated by $(\sigma_D^2-\sigma_S^2)/(\sigma_S^2+\sigma_D^2+\sigma_R^2)$.

TABLE 3

Estimates of the heritability and litter variance of carcass traits

	Heritability	s.e.	Litter variance	s.e.
Tissue in side (%)				
Lean	0·41	0·13	0·10	0·07
Bone	0·16	0·10	0·25	0·07
Total fat	0·37	0·13	0·18	0·06
Subcutaneous fat	0·36	0·13	0·15	0·07
Intermuscular fat	0·37	0·13	0·04	0·07
Kidney knob and channel fat (KKCF)	0·37	0·13	0·15	0·07
Lean/bone ratio	0·13	0·09	0·18	0·07
Lean/fat ratio	0·46	0·14	0·15	0·07
Subcutaneous/intermuscular fat ratio	0·12	0·09	0·08	0·07
Subcutaneous fat depth	0·21	0·11	0·17	0·07
Eye-muscle area	0·14	0·10	0·19	0·07
Lean weight/day of age	0·23	0·11	0·42	0·07
Subcutaneous fat score	0·27	0·10	0·10	0·07
Conformation score	0·18	0·12	0·13	0·06

Correlations

The phenotypic correlations between weights at different ages were high and, as expected,

declined as the time between measurements increased (Table 4). Where growth rate traits contributed to weight for age traits their correlations were high, but otherwise they were low. Due to negative sire variance components, some genetic correlations could not be estimated, and others were variable and unreliable due to the low sire component estimates.

Phenotypic and genetic correlations between ADG birth to slaughter and lean weight/day of age were positive and high (Table 5). The genetic correlations of these two traits with carcass composition indicated negative relationship between growth rates and percentage fat and lean/bone ratio. The genetic correlations amongst carcass traits were not unfavourable in terms of the overall selection objectives of increased percentage lean and lean/bone ratio and reduced percentage fat in the carcass. However, increased percentage lean and lean/bone ratio at a constant live weight were not compatible with a high ratio of subcutaneous/intermuscular fat.

The phenotypic correlations between subcutaneous fat depth and percentage carcass composition were moderately high but the phenotypic relationships between eye-muscle area and carcass traits were poor. The genetic correlations of subcutaneous fat depth and eye-muscle area with carcass composition were moderately high. Visual assessment scores of subcutaneous fat cover and conformation were positively correlated with carcass fatness.

DISCUSSION

The results presented for the heritability of pre-weaning live weight and growth rates are in good agreement with published estimates for Down cross lambs (e.g. Bowman and Hendy, 1972). Bowman (1968) has suggested that the consistently low heritabilities of live-weight growth found for Down cross sheep may be due to reduction in genetic variation through previous selection in these breeds, and cites examples of higher heritability found in unselected American range sheep. It is possible that the use of crossbred lambs in this and other studies has led to low heritability estimates. However, the limited information available suggests that heritability is similar or higher in crossbred progeny (Ercanbrack and Price, 1972).

The low heritability estimates for early growth and weight are usually attributed to the importance of variation in dam effects, especially in milk production, and to competition between littermates; and the estimates tend to increase with age (e.g. Olson, Dickerson and Glimp, 1976). Some authors (e.g. Gjedrem, 1967) have found higher heritability estimates in singles than in twins, but this was not so in the current data, or in other more recent ABRO analyses (T. G. Martin, personal communication). Higher effective heritabilities for weight for age have been found for artificially reared lambs (Owen *et al.*, 1978), and this offers a useful but elaborate testing method in selection. However, in a recent analysis of a large volume of farm records of purebred Dorset Down and Suffolk United Kingdom flocks (P. Bampton, personal communication), where within flock adjustments were made for effects of dam age, rearing type and other factors, a heritability of 0·19 (s.e. 0·03) was found for 8-week lamb weight. Thus selection for weight at 8 weeks, and later ages, on adjusted field records may, after all, be a useful and practical method for improving early lamb growth.

The heritability estimates of percentage carcass composition and lean/bone ratio were in good agreement with those presented by Botkin, Field, Riley, Nolan and Roehrkasse (1969). Heritability estimates for subcutaneous fat depth and eye-muscle area tended to be lower than previously published results (Botkin *et al.*, 1969; Bowman and Hendy, 1972; Cotterill and Roberts, 1976). These results indicate that genetic selection to change carcass composition at a fixed live weight should be successful. However, the ratio of lean to fat is more amenable to selection than the lean/bone or subcutaneous/intramuscular fat ratios. This is an important result in view of the widespread consumer resistance to animal fat and the specific problem of over-fatness in the lamb carcass (Kempster, 1979).

The difficulties of estimating carcass composition in the live animal may dictate the use of a progeny test with its disadvantages of higher cost, lower selection intensity and increased generation interval relative to the performance test. Thus the correlation between traits which can be measured in the live animal and its carcass composition are of particular interest. Although the genetic correlations between ADG birth to slaughter and measures of

TABLE 4

Correlations† (×100) amongst live-weight growth traits

		(1)		(2)		(3)		(4)		(5)		(6)		(7)	(8)	(9)		(10)		(11)
			s.e.		s.e.		s.e.		s.e.		s.e.		s.e.				s.e.		s.e.	
Birth weight	(1)			55		49		43		26		23		19	10	28		−30		3
4-week weight	(2)	−‡				83		74		67		93		26	18	59		−57		22
8-week weight	(3)	−11	69	—				88		84		76		76	18	73		−67		28
12-week weight	(4)	22	58	—		114	15			68		68		65	63	79		−73		26
ADG birth-12 weeks	(5)	0	62	—		120	20	98	3			68		66	66	79		−72		28
ADG birth–4 weeks	(6)	—		—		—		—		—		—		23	17	58		−54		24
ADG 4–8 weeks	(7)	−27	67	—		132	32	157	54	168	60				11	56		−50		23
ADG 8–12 weeks	(8)	—		—		—		—		—		—		—		45		−40		9
ADG birth–slaughter	(9)	−44	96	82	177	65	25	71	21	77	15	73	41	—	—			−88		29
Slaughter age	(10)	88	141	−31	115	−54	35	−44	40	−57	36	−66	50	—	—	−98	5			−7
Killing-out %	(11)	−72	88	−3	112	14	39	−3	43	5	36	32	50	—	—	53	21	−52	31	

†In this and following Table, phenotypic correlations above the diagonal, genetic correlations below.
‡Values cannot be estimated because of negative sire components.

TABLE 5

Correlations (×100) between some carcass traits and ADG birth to slaughter

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
		s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	s.e.	
ADG birth–slaughter	(1)		8	3	−7	3	−7	−27	−0	4	8	8	3	94	−0	20
% Lean	(2)	15 29		41	−93	−83	−77	−60	22	88	−26	−61	9	21	−47	−38
% Bone	(3)	80 37	67 22		−71	−64	−47	−54	−79	63	−34	−50	−26	−1	−43	−52
% Total fat	(4)	−32 29	−98 2	−82 12		91	79	68	14	−93	34	68	4	−15	53	49
% Subcutaneous fat	(5)	−47 41	−98 7	−31 42	92 6		50	50	12	−83	67	69	8	−5	53	52
% Intermuscular fat	(6)	−27 24	−75 9	−77 21	83 8	57 19		38	−1	−74	−29	43	−0	−16	33	33
% KKCF	(7)	−27 27	−67 14	−84 14	77 10	74 19	35 18		19	−62	23	42	−1	−28	32	26
Lean/bone ratio	(8)	−89 39	36 31	−45 26	−15 31	−64 46	0 26	15 25		−9	17	12	33	13	14	28
Lean/fat ratio	(9)	28 26	94 3	81 12	−97 2	−88 9	−84 7	−70 9	12 24		−35	−57	−5	13	−50	−48
Subcutaneous intermuscular fat ratio	(10)	−57 39	−58 26	41 44	38 25	31 33	−60 21	58 21	−119 47	−34 20		37	10	7	33	32
Subcutaneous fat depth	(11)	−30 39	−80 15	−14 45	74 16	80 14	50 17	55 23	−61 42	−64 18	18 34		5	4	45	40
Eye-muscle area	(12)	38 31	53 29	−12 44	−42 33	−56 41	−7 26	−56 30	64 30	38 29	−54 38	−47 39		44	13	29
Lean weight/day of age	(13)	95 3	41 24	93 30	−56 22	−75 32	−42 20	−33 20	−75 32	55 3	−80 7	−47 32	49 24		−1	21
Subcutaneous fat score	(14)	−23 29	−85 12	−59 19	85 10	78 18	39 18	73 13	−30 28	−81 9	82 33	73 20	−19 32	−34 21		64
Conformation score	(15)	7 32	−79 18	−60 20	81 14	66 30	46 26	49 19	−21 33	−77 11	26 32	44 36	40 38	−16 25	100 7	

fatness were low and had large standard errors, their size and sign is in agreement with a summary of estimates from beef cattle experiments with constant slaughter weight end-points (Barlow, 1978). The unfavourable genetic correlation between growth rate and lean/bone ratio is of some concern. However, the low heritability and phenotypic standard deviation for this trait may mean that the correlated response to selection for growth rate may not be severe.

Ultrasonic equipment allows the estimation of subcutaneous fat depth and eye-muscle area in the live animal. The phenotypic correlations of these two traits with carcass composition confirm that the former would provide a good estimator of lean percentage while the latter has low predictive value for carcass composition (e.g. Kempster, Avis, Cuthbertson and Harrington, 1976).

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